APR 21 1936

THE AMERICAN WELDING SOCIETY JOURNAL

VOLUME 15 APRIL 1936 NUMBER 4

PUBLISHED MONTHLY FOR THE ADVANCEMENT OF THE SCIENCE AND ART OF WELDING

Part of the equipment fleet operated by Massachusetts Welding Company, and (insert) the genial and dynamic Frank O'Rourke, who started the business and manages it today.

From the largest welding shop in Massachusetts...

praise for TOBIN BRONZE

Telephone | Col. 0813 Col. 0296 Fay. 3313

MASSACHUSETTS WELDING COMPANY

Automobile Bodies, Radiators, Fenders, and Tanks Repaired
Contractors' Equipment and Machinery Repairs
Brazing and Casting

Electric and Acetylene Welding
79 CLAPP STREET, CORNER MASSACHUSETTS AVENUE
BOSTON, MASS.

Radiators Re-Cored and Repaired
Ship Work and Marine Boilers
Specialists in Thawing Frozen Water Lines

March 26, 1935.

The American Brass Company
Waterbury
Connecticut.

Gentlemen:

During the past 15 years, our welding business has increased tremendously. We attribute our growth to these three facts: (1) Our workmen are trained to produce A-1 work. (2) We use only the best grade of stock. (3) Our prices are fair.

The use of good stock is one of our fundamental policies. Good stock builds Good Will for our shop. Therefore we recommend genuine Tobin Bronze and use it exclusively as we have since our business was started 15 years ago.

Very truly yours,
MASSACHUSETTS WELDING CO.
Frank O'Rourke

From a two-man shop operating one truck to the largest business of its kind in the state of Massachusetts . . . in the short space of fifteen years! That is the achievement of the Massachusetts Welding Company of Boston under the management of Mr. Frank O'Rourke.

During his years in the welding business, Mr. O'Rourke has always used good stock . . . Tobin Bronze. Read his letter, reproduced here. It tells you what he thinks of the original low melting point bronze rod.

Don't gamble with an unproved rod. Ask for and get *genuine* TOBIN BRONZE. It carries the name stamped every 12 inches in each rod.

ANACONDA
from mine to consumer

THE AMERICAN BRASS COMPANY
General Offices: Waterbury, Connecticut
Offices and Agencies in Principal Cities
In Canada: ANACONDA AMERICAN BRASS LTD.
New Toronto, Ont.

ANACONDA WELDING RODS

THE
AMERICAN WELDING SOCIETY
JOURNAL

WM. SPRARAGEN, Editor | VOL. 15 | NO. 4

AMERICAN
WELDING SOCIETY

PUBLICATION OFFICE
20th and Northampton Sts.,
Easton, Pa.

EDITORIAL AND
GENERAL OFFICES
33 West 39th St.,
New York, N. Y.

OFFICERS FOR 1935–36

President
J. J. Crowe

Treasurer
C. A. McCune

Senior Vice-President
E. R. Fish

Secretary
M. M. Kelly

Divisional Vice-Presidents
A. G. Leake, New York & New England
T. C. Smith, Pacific Coast
W. W. Reddie, Middle Eastern
C. L. Eksergian, Middle Western
E. E. Dillman, Southern Division

SECTION HEADQUARTERS

PHILADELPHIA
Engineers' Club, 1317 Spruce St.

CHICAGO
608 South Dearborn St.

PITTSBURGH
Room 906, House Building

NEW YORK
33 West Thirty-Ninth St.

NORTHERN NEW YORK
General Electric Co., Schenectady, N. Y.

CLEVELAND
410 Hanna Building

SAN FRANCISCO
Park Ave. & Halleck St., Emeryville, Cal.

LOS ANGELES
8976 San Miguel Ave., South Gate

BOSTON
Engineering Societies of New England
715 Tremont Temple

WESTERN NEW YORK
500 Morgan Bldg., Buffalo, N. Y.

DETROIT
Paramount Welding Supply Co.
5950 Second Blvd.

PORTLAND, ORE.
P. O. Box 1899, Station F

MARYLAND
516 N. Charles Street

MILWAUKEE, WIS.
2841 N. 51st Street

APRIL

Contents

Technical Papers, Items and Reports

Page

Welded 38-Ft. Diameter Sphere for Storage of Butane 150 Lb. per Square Inch Pressure. (Courtesy Chicago Bridge & Iron Co.) . . . . . Frontispiece

Impact Tests of Welded Joints, by *W. Spraragen* and *G. E. Claussen* 2

Welded Highway Bridge, Burlington County, New Jersey, by *W. K. Greene* and *C. W. Wixom* 12

Fusion Welding of Bridges, by *P. G. Lang, Jr* 16

Gas Welding of Class I Pressure Vessels, by *G. W. Plinke* 20

Fundamentals of Spot Welding with Particular Reference to Electrode Life, by *E. I. Larsen* 25

Requirements for Repairs by Fusion Welding on Boilers and Pressure Vessels 31

Current Welding Literature 32

Society and Related Activities

Annual Meeting Combined with Fall Meeting 33

Proposed Federal Specification 33

Another Use of Arc Welding Apparatus 33

M. Bayard Butler, Jr 33

Employment Service Bulletin 33

Section Activities 33

By-Law Amendments Effective April 10, 1936 34

Summary of Replies Received to Questionnaire of Meetings and Papers Committee up to April 1st 35

Translations 35

XIIth International Congress 35

Fusion Welding of Highway and Railway Bridges 35

ISSUED MONTHLY

The Society is not responsible for any statement made or opinion expressed in its publications. Permission is given to reprint any article after its date of publication, provided proper credit is given.

Copyright, 1936, by the American Welding Society

Subscription $4.00 per year in United States and possessions; $4.50 in Canada, Foreign Countries, $5.50.

Entered as second-class matter January 15, 1932, at the post-office at Easton, Pa., under the Act of March 3, 1879.

Impact Tests of Welded Joints

A Review of the Literature to January 1, 1936

By W. SPRARAGEN* AND G. E. CLAUSSEN**

Introduction and Summary

IN MANY engineering applications such as bridges, ships, cranes and piling, welds are subjected to dynamic stresses of an "impact" character. It is important for engineers as well as for others to know to what extent welds are able to withstand such stresses and the relation, if any, between impact resistance and other physical properties and how one may best improve impact resistance of welded joints.

This report as its title indicates is a review of the literature on the subject divided into four main divisions: (1) Methods of making impact tests of welded joints; (2) Results obtained from impact tests; (3) Service tests and results, and (4) Bibliography.

As may be expected, most of the tests have been made with the standard Izod and Charpy specimens, although the results of a number of tensile impact investigations are available. Several European countries require impact tests of welded specimens in codes and specifications. There is no such requirement, as yet, in the United States.

Impact values of welded joints have steadily improved from 4 ft.-lb. for the standard Izod specimen to 40 and 50 ft.-lb. at the present time. There are many important factors which affect the impact test results, notably, type of filler metal, process of welding, method of depositing weld, heat treatment and the avoidance of stress concentrations. Service results indicate conclusively that even welds made with bare wire will withstand severe impact stresses. With superior filler metal by both gas and arc it is possible to produce welds having nearly the same resistance to impact as the base metal. There is a decided lack of information on impact of welds in non-ferrous metals and welds made by the resistance and thermit processes. Meager test results and service experience indicate that good welds by these two last named processes give excellent impact results. Welds subjected to extremely low or high temperature merit special consideration and good results are entirely feasible.

I—Methods of Making Impact Tests

Laboratory Tests

National and Other Standards. The obvious desirability of testing welds for impact resistance has not led to the adoption in the U. S. A. of a standard laboratory impact test. Standard welding specifications of at least five countries, however, contain detailed instructions for the impact testing of welds or welding electrodes. Although all these specifications require a notched-bar specimen in impact bending, there are considerable variations among the specifications in two principal respects:

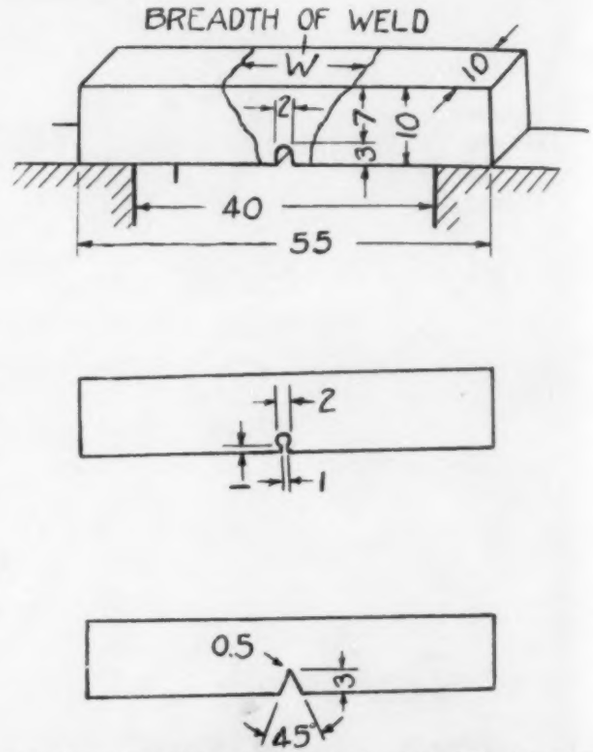


Fig. 1—German Standard Impact Specimens for Gas and Arc Welds. Upper—Round Notch, Milled. Middle—Round Notch, Drill Hole and Saw Cut. Lower—Sharp Notch. (Dimensions in Millimeters)

(1) Type of specimen, Izod or Charpy (Mesnager),
(2) Specimens prepared from an actual welded joint or from all-weld-metal.

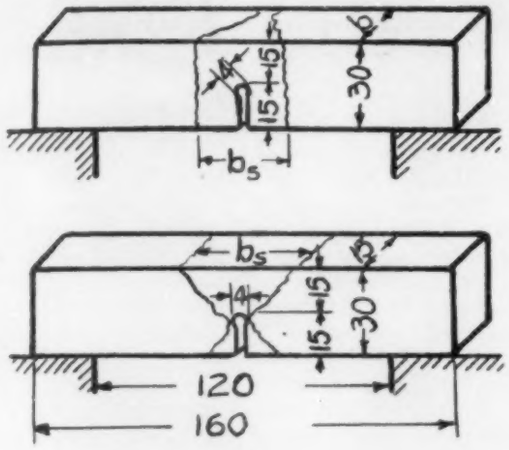
Since it appears unlikely than an internationally standardized notch-impact specimen even for unwelded metal will be adopted for some time, the existing differences between specifications may be expected to remain indefinitely.

German

The standard notch-impact test adopted in Germany, from which has come most of the impetus for standardizing the impact test, is described in D. I. N. 1913.[1] An almost identical standard has been adopted in Austria.[2] The standard specimens, shown in Fig. 1, are cut from welds made in horizontal plates 350 x 150 mm. Impact tests are not made on plates thinner than 10 mm. The weld is deposited in a V (70 deg. angle) for plates up to 12 mm. thick and in the form of notch dictated by shop practice for plates thicker than 12 mm. From forgeable welds two specimens are taken, from unforgeable, three specimens. Either the 10 kgm. or the 30 kgm. pendulum machine is used with a hammer angle of 30 deg. Of the three types of notch shown in Fig. 1 the first two are

This report is a contribution to the work of the Engineering Foundation Welding Research Committee.
* Secretary, Fundamental Research Committee.
** Research Assistant, Fundamental Research Committee.

Fig. 2—Notch Impact Specimens. Vereinigung Grosskesselbesitzers (VGB). Dimensions in Mm. Upper Specimens for Plate Thickness
S = 12 to 30 mm. For S = 12 to 15 mm., $b = S$
For $S > 15$ mm., $b = 15$ mm.
in Which Case One Plate Surface Is Not Machined. Lower Specimen for $S > 30$ Mm.; in This Case the Upper Specimen May Also Be Used



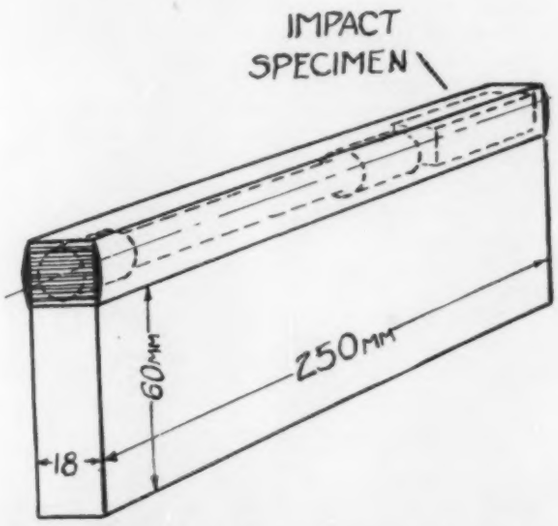


Fig. 3—Standard Method of Preparation of All-Weld-Metal Impact and Tensile Specimens Specified by French Society of Welding Engineers and Others for Gas Welding

ordinarily used; the upper specimen is adopted when the notch is milled, the lower when the notch is drilled and sawn. The sharp-notch alternative specimen is used for tough material that cannot otherwise be broken with a single blow. The round-notch specimens are identical in dimensions with the Mesnager specimen, except that the notch depth is 3 mm. instead of 2 mm. to promote ease in drilling key holes. The impact value is expressed in meter kilograms per square centimeter of cross section back of the notch. In heavy plate over 15 mm. both specimens may be cut from different cross sections of the weld.

Although the impact value is included in the test report, the D. I. N. impact test is not an acceptance test unless it is so specified by special agreement between purchaser and manufacturer. The impact value is considered to indicate (1) the behavior of a material under sudden loads, (2) the character of deformation beyond the elastic region, (3) the degree of forgeability and (4) mistakes in heat treatment (annealing at too high a temperature, etc.).

For welded vehicles the German Federal Railways requires deposits of electrodes and gas welding rods to attain the following values:

Electrodes,	E 34 h	8 mkg./cm.^{2} unannealed
	E 34 h	10 mkg./cm.^{2} annealed
	E 37 h	5 mkg./cm.^{2} unannealed
	E 52 h	5 mkg./cm.^{2} unannealed
Gas welding rods	St 34	8 mkg./cm.^{2} unannealed
	St 34	10 mkg./cm.^{2} annealed
	St 37	5 mkg./cm.^{2} unannealed
	St 52	5 mkg./cm.^{2} unannealed

The standard D. I. N. specimen is used but when an old-type machine only is available a specimen may be used of which the length is 100, the distance between supports 70 mm., and other dimensions the same as the D. I. N.

Two other specimens often used in Germany are those prescribed by the Instructions of the Boiler Owners Society (V. G. B.). In addition to the small German standard (D. I. N.), the V. G. B. has adopted two large specimens, shown in Fig. 2. A mechanical aging test is also specified for boiler plate. Prior to testing in impact the weld is stretched 7 to 9% in tension and aged $^1/_2$ hour at 250° C.

French

The standard impact test for gas welds in France is that contained in the Specifications of the Joint Commission of La Société des Ingénieurs Soudeurs and l'Institut de Soudure Autogène drawn up for adoption in January 1936.[3] The specimens adopted, Fig. 3, are identical with the German standard except for notch dimensions. The Mesnager notch is 2 mm. deep; the Charpy notch is 5 mm. deep. The Charpy specimen is that standardized by the Association Française de Norm. The impact test specimens are machined from all-weld-metal deposited in 18 or 20 runs about 1 mm. thick on a plate 15 to 20 mm. thick and 250 x 60 mm. cross section. The specimens must be cut at least 5 mm. from the bottom of the deposit. Torch speed, burner and rod instructions are given. The weld metal must pass the following requirements:

	R	A	K	H	S and $S-P$
Material	$\geqslant$	$\geqslant$	$\geqslant$	$\geqslant$	
A-40	35	20	10	100	$\leqslant 0.04$; $S + P < 0.07$
A-50	45	14	8	120	$\leqslant 0.04$; $S + P < 0.07$
A-60	55	10	6	140	$\leqslant 0.04$; $S + P < 0.07$
A-70	60	8	4	200	$\leqslant 0.04$; $S + P < 0.07$

R—tensile strength, kg./mm.^{2}
A—elongation in % of gage length of 7.2 diameter
K—notch impact value, kgm./cm.^{2}
H—Brinell hardness

The above steels with 0.5% Cu have the same specifications.

These requirements for gas welds are similar to the various specifications for arc welds. For all-weld-metal specimens of 50,000 psi tensile grade an impact value of 5 mkg./cm.^{2} Mesnager specimen is required in marine and general structural work by Le Bureau Veritas.[4] The French standard Charpy is adopted in the Instructions of the Department of Roads and Bridges[5] who require 8 mkg./cm.^{2} for electrodes of both the 50,000 and the 60,000 psi classes.

British

The British standard impact test for arc welds is described in British Standard Specification No. 538–1934.[6] The standard Izod specimen, Fig. 4, is machined from all-weld-metal. Three impact tests are made on every 50,000 ft. of No. 8 S. W. G. electrode or with other sizes an equivalent weight. At least two of the three shall give an impact value of not less than 30 ft.-lb.

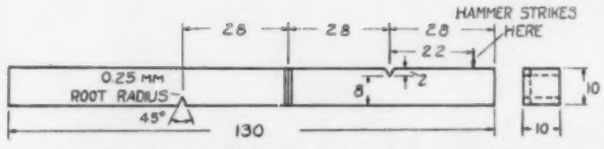


Fig. 4—British Standard Izod Specimen (All-Weld-Metal). Dimensions in Millimeters
Note: The unnoted side of the specimen is that immediately adjacent to the plate on which the metal is deposited.

The standard Izod specimen (three-notch) is also specified by Lloyds Register. Two standard specimens must give an average Izod value of 20 ft.-lb. according to their "Additional Tests for Electrodes Proposed to Be Used for Parts of Primary Structural Importance, 1934–1935."

Australian

Although the Standards Association of Australia[7] also specifies the standard Izod specimen, it is cut from an actual butt-welded joint, Fig. 5. The standard notch is located on the center line of the weld and on the open side of the 90 deg. V. For Australian Structural Grade Electrodes the average Izod value of 5 specimens must be not less than 30 ft.-lb.; for Ordinary Grade the minimum is 20 ft.-lb. The specifications of the Northwestern Railway, India, contain conditions and requirements for impact specimens that are identical with S. A. A. No. CA 8.

The S. A. A. Boiler Code CB 1 No. B 28–1931 and No. B 29–1931 uses a standard Izod specimen milled from butt-welded plates having a 70 deg. V. Five unannealed specimens must average at least 25 ft.-lb. both for arc and gas welds.

So far as can be ascertained, the national standards of all other countries, including France, specify no impact tests for welds. Furthermore, all the standards that have been described relate to steel and to specimens that have been machined on all sides. The impact test for welded joints was deleted from the final form of the A. S. M. E. Boiler Code because the Code Committee determined that only welds having satisfactory impact value could meet the Code's physical requirements.

Comparison of the standard tests with each other shows that there is lack of agreement between the different standardizing bodies on two major issues.

1. Whereas the impact test for unwelded material standardized in the countries of Continental Europe is the Charpy, that adopted in Great Britain and Australia is the Izod. It is therefore natural that a similar division should exist in the impact test for welds. The Charpy keyhole notch is fundamentally superior to the Izod nick but is somewhat more expensive to machine.

2. The intention of the standard impact tests on all-weld-metal is solely to test the quality of the welding rod as reflected in the cast deposit. The aim of the tests using actual joints appears to be to test the quality of the deposit in contact with parent metal. In the latter instance, normal welding conditions are reproduced but the absorption of impact energy by parent metal must be anticipated, especially in specimens notched on the open side of the weld. Results from specimens notched on the root side average the impact-absorbing capacity of the annealed inner and the unannealed outer layers of arc welds.

Other Impact Tests for Welds

Although much of the research on impact properties of welds has been performed on standard specimens of the notched type, a number of investigators have used specimens of their own design or other methods of testing impact properties, and a few have studied the effect of variations from standard specimens in an effort to improve their sensitivity. Of this last group the work of Schuster[8] on the Izod specimen, who showed that a 10 x 5-mm. Izod specimen with 1-mm. notch depth was as sensitive as the standard Izod for actual joints, of the British Engine, Boiler and Electrical Insurance Company[9] whose results on 10-mm. and 8-mm. Izod specimens reveal no simple conversion factor, and of Dustin,[10] and Bardtke and Matting[11] on the Charpy type appear most important.

Dustin showed that the standard Mesnager and Charpy specimens for welded joints gave relatively little scatter but that the Charpy was slightly better in this respect, that nothing was to be gained by increasing the dimensions of the standard specimens, and that varying the proportion of weld metal to parent metal in the specimen within wide limits had no effect on impact value. Elongation and impact value apparently measured the same quality though the impact figure was the more sensitive. Dustin's results made it clear, however, that impact tests on specimens whose "zone of transition" occurred in the neighborhood of room temperature were likely to be erratic and misleading. The disturbing effect of this narrow zone of temperatures, which is a characteristic of steel and in which impact value, apparently related to the variation with temperature of the ratio of shear to tensile stress developed in the Izod or Charpy test, falls from a high to an exceedingly low value within a range of perhaps 30° C., is acute in materials of heterogeneous grain size and composition.

From a short series of tests on various forms of specimens in which dimensions of specimen were changed as well as the location of notch with respect to weld, Bardtke and Matting report in favor of the D. I. N. Mesnager specimen with 3-mm. notch depth. The drilled notch

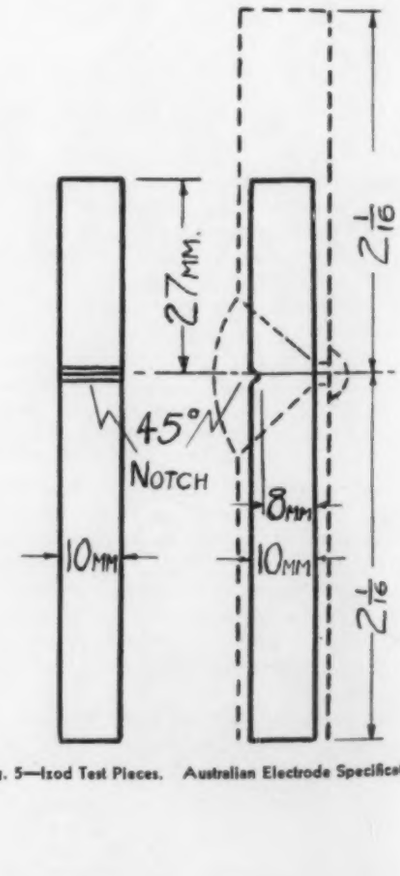
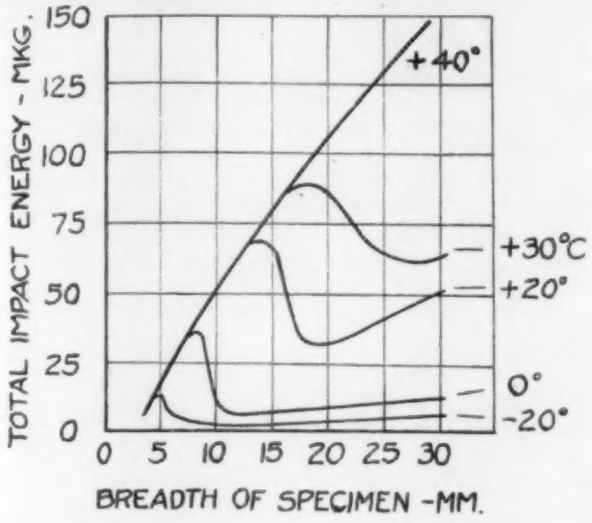


Fig. 5—Izod Test Pieces. Australian Electrode Specifications

Fig. 6—Energy of Fracture as a Function of Breadth of Specimen and Temperature of Test for Mild Steel. Length of Specimen—110 Mm. Depth Behind Notch—15 Mm. Notch—5 Mm. Deep; 45° Included Angle Velocity of Impact—5.5 M/S. (Moser 1924)



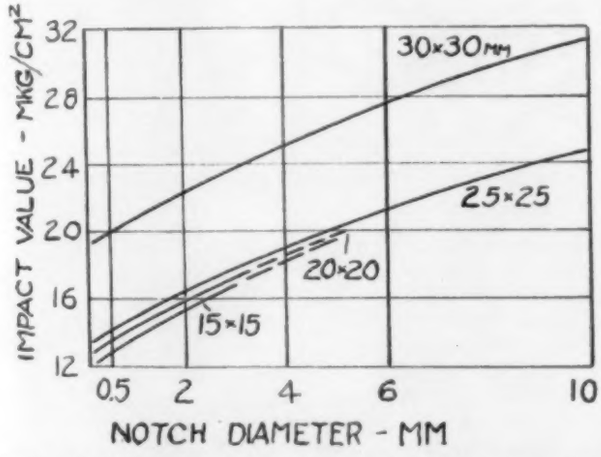


Fig. 7—Relation between Cross-Sectional Area, Diameter of Notch and Impact Value for Mild Steel at 200°C. (Distance between Supports = 120 Mm.) (Mailander, 1926)

gave slightly higher values than the milled. As in unwelded specimens, the impact value of welded specimens of mild steel is independent of pendulum velocity between 3 and 5.2 meters per sec. A more complete series of tests on the correlation of impact values obtained on standard specimens with the results of other standard welding tests, such as tensile, bend and fatigue, would be of obvious value.

The Impact Test in General

It is not surprising that there has been no success as yet in developing rules or formulae by which to reduce the impact value of welds determined on different types of notched specimens to a value corresponding to a standard specimen. Although many reduction formulas have been suggested for unwelded materials all have failed. In spite of the fact that one of the chief recommendations of the impact test is its ability to locate the zone of transition in steel, all reduction formulas fail to account for it; nor has any proposed rule been successful in relating impact value with any of the many variables of the test.

The variation of impact value with the dimensions of specimens is much more complex than the simple beam formula would lead us to expect. Although it is well known that for a fixed form of notch and fixed total depth of specimen the impact value is roughly proportional to depth back of notch in brittle materials and to the square of the depth in tough materials, the value usually lies between these two limits, and a scatter of ±25%, according to Burns,[12] is to be anticipated. Relations between impact value and breadth of specimen have been reported and appear to be valid for some non-ferrous metals, but in view of the non-uniformity in degree of deformation across the specimen, no close relation would be implied theoretically. For mild steel the relation of breadth to impact value is by no means simple, as Fig. 6 will show.[13] The relation between impact value and cross-sectional area, as well as diameter of notch is also complex; in Figs. 7 and 8 (Honegger's Figs. 15 and 16) for mild steel at +200 and −70° C. Mailänder's[14] results show that specific impact value is independent of notch diameter only with brittle materials. He shows, too, that once a crack is formed at the base of the notch, the notch radius becomes infinitely small and the ratio of breadth to depth is increased. It is claimed that there is complete equivalence between the round and square standard British Izod specimens.

The absence of proportionality between impact value and cross-sectional area back of the notch may be due as much to design of machine as to type of specimen. With their new suspension-type of impact machine Roberts[15] and Southwell found for a number of materials that there is strict proportionality between impact resistance and cross section back of the notch. Perhaps the losses of energy in the machine foundation, in the hammer and in resonance effects, which amount to over 15% on the usual Charpy machine according to Dubois,[16] may partly account for the complex nature of impact results.

There are two variables at any rate in the impact test whose variation does not have much effect on impact value. The distance between supports may be varied without appreciable effect on impact value. If, however, the supports are brought too close together, the results are complicated by the phenomenon of shear. The effect of changing the velocity of impact within the usual limits of the machine is also negligible, except possibly in every tough material. It must be admitted that the range of velocities that has been tested is not convincingly large; whether velocities encountered in ordnance introduce other impact effects is apparently not known. Information of the sort furnished by the high-speed tensile impact tests of the Watertown Arsenal for unwelded materials would be valuable for evaluating the characteristics of welds.

Mailänder's curves, Fig. 9, showing that between four types of impact specimen there is a difference of 20° C. in the apparent position of the zone of transition forms a

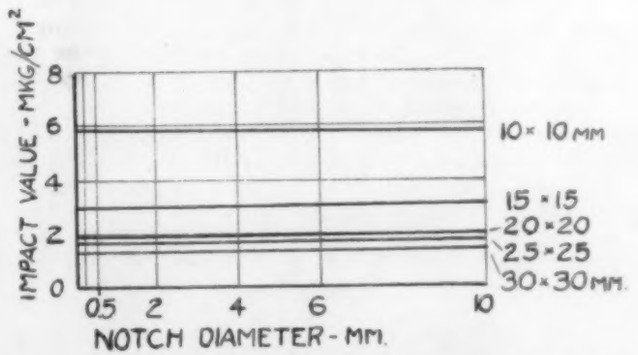


Fig. 8—Relation between Cross-Sectional Area, Diameter of Notch and Impact Value for Mild Steel at − 70° C. (Distance between Supports = 120 Mm.) (Mailander, 1926)

fitting conclusion to this digression on conversion formulas. It appears that the suggestion of László[17] is still pertinent: experimentally determine curves relating all the variables in the impact test. The recent work by Burns, cited above, is a direct application of this principle. In the impact testing of all-weld-metal the principle is relatively easy to apply, but when V weld specimens are tested even this principle may be unsatisfactory. Position of notch with respect to the center line of the weld and relative percentage of overheated parent metal participating in the deformation are two knotty variables introduced by V or double V weld specimens.

Notch Location

Variations from the standard specimen have been introduced mainly to obtain a more satisfactory location of notch. Several variations of notch location are shown in Fig. 10. The notch has also been located variously with respect to center line of plate or seam; e.g., at the transition between parent metal and weld, in the overheated zone. Except that they fulfilled the immediate purpose of the particular investigator, little can be said of these variations for none has been correlated with results on standard specimens. Whether, for example, Kleiner and Bossert's modification subjects more zones of the weld to impact without introducing misleading complications, it is not yet possible to state. The standard V. G. B. specimens used different notch locations depending on plate thickness. Söhnchen and Kleinefenn[28] state that the mixed notch has about 20% higher toughness but in plate sensitive to aging this relation may be reversed. However, in double V welds, specimens with notch perpendicular to the surface of the plate have up to 20% less impact value than specimens with notch in the face of the weld. Between the three locations of notch tested by Bardtke and Matting practically no difference in Charpy value was observed. Jennings[29] also found very little difference between these three locations using the Izod notch in V welds. Hodge[30] found that the horizontal longitudinal and horizontal transverse locations of notch in weld metal gave approximately equal values but that the vertical specimen gave higher values because fracture had to extend across the original columnar crystals of the deposit. The Izod value of all-weld-metal appears to be about 50% greater when the notch is parallel to the direction of deposition than when it is perpendicular.

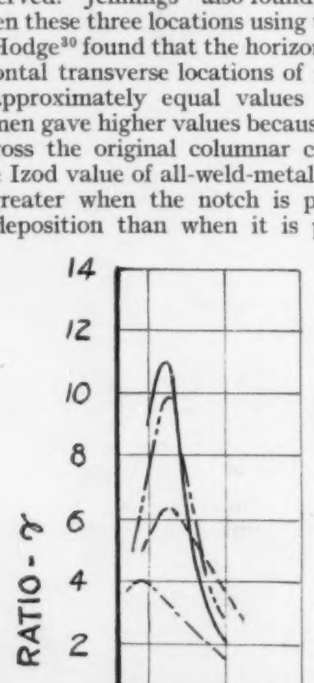


Fig. 9—Difference between Correctly Annealed and Overheated Notch-Impact Specimens of Four Different Types

$$\text{Ratio} = \frac{\text{Impact Value Correctly Annealed}}{\text{Impact Value Overheated}}$$

(Mailander, 1935)

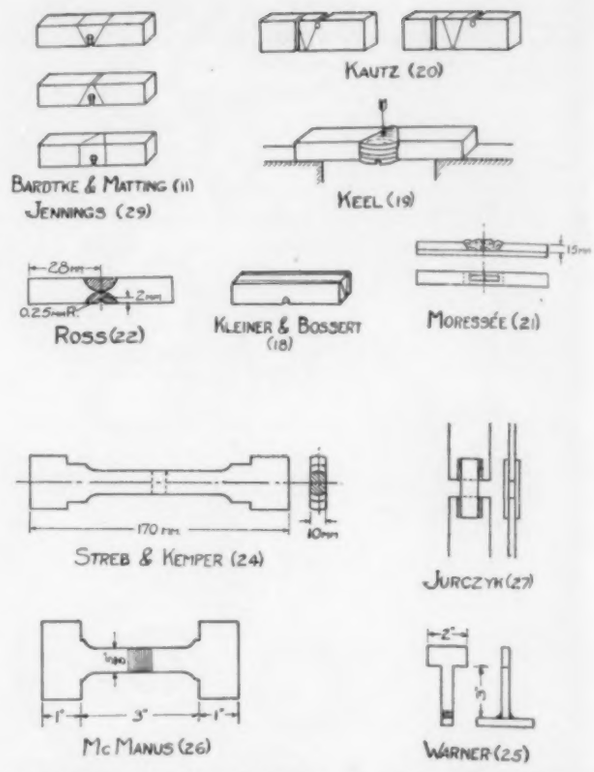


Fig. 10—Notch-Impact and Tensile-Impact Specimens Used by Various Investigators

Although a specimen such as Keel's, from which reinforcement is not removed, is advantageous in some respects, Rüter[31] and Söhnchen[28] have shown that the removal of reinforcement usually increases the impact value. It has been pointed out that from the standpoint of sensitivity to impact the most dangerous region in a welded joint is at the junction between reinforcement and parent metal. The junction acts as a notch and a photoelastic study has shown that a 70% increase in stress in the vicinity of this junction is to be expected under static load. The variation with specimen dimensions of the impact value of welds appears to follow the same rule as that which applies to unwelded material: the larger the specimen the greater the apparent toughness until, when a critical size is reached, the impact value abruptly falls with further increase in cross-sectional dimensions. On this account the Continental practice of expressing impact value as kgm./cm.^{2} of cross-sectional area is scarcely appropriate.

The single-blow impact test has often been used to test unnotched specimens of unwelded materials but the results have generally been notoriously untrustworthy. This has also been confirmed by the results of Menetrier[32] in whose tests the scatter for welds of presumably identical quality amounted in several cases to over 100% from the average. Lohmann,[33] however, found no difficulty with unnotched Charpy specimens of welds, although the unnotched gives somewhat different information from the notched specimen. The notched specimen is particularly useful for detecting the presence of embrittling metallographic constituents, such as nitrides, that are deposited during aging or in slow cooling after annealing, and for locating the temperature of the zone of transition; it does not reflect the tensile properties of weld or parent metal. The impact value of unnotched specimens, on the other hand, is increased as the strength of parent metal increases; furthermore, the zone of transition may or may not be detected, depending on chemical composi-

tion, and, in all cases, annealing a little above Ac_3 increases the impact value of unnotched specimens. Thus the unnotched specimen seems to be influenced to a greater extent by the increase in ductility (percentage elongation) than by the decrease in strength or by the precipitation of embrittling constituents consequent upon annealing. The unnotched specimen may give lower impact values than the notched if the notch extends beyond the depth of a coarsely crystallized zone, as Ros[29] has shown. Primarily, the unnotched specimen gives information about the quality of surface and junction zone, as well as about the degree of penetration.

Tensile and Repeated Impact

The desirability of testing all zones of a single welded joint in impact—with notched-bar specimens this is practically impossible—has led to the use of the tensile impact test for welds. The usual procedure for tensile impact testing is to rupture a tension specimen, usually of small cross section, so fitted in the anvil or hammer of a pendulum machine that the axis of the specimen coincides with the tangent to the path of the hammer at the instant of fracture. In this country the test has been used particularly by the Navy and Army testing laboratories, who appear to favor rather large cross sections, e.g., $^1/_2$ in. x $^5/_8$ in.; both butt and fillet welds are tested. Others who have used the test: Bock,[34] Hoffmann,[35] Fiek and Hoffmann,[36] and Streb and Kemper,[24] feel that the test would be ideal for weld testing were it not that the size of specimen is limited by the comparatively small capacity of the usual impact testing machine. The test appears to be particularly valuable as a means of determining the relative capacity of the various zones of a welded joint for deformation under impact and without the influence of a notch or, in some cases, machining. It thus indicates the extent to which the behavior of the weld resembles parent material.

The resistance of welds to repeated light impacts (impact fatigue) has also been used as a substitute for the single-blow test. The repeated impact test distinguished clearly between bare and coated electrodes in a series of tests conducted by the British E. B. & E. Insurance Co. But the Vereinigte Stahlwerke Dortmund found that the Schenck Repeated Impact machine graded electrodes according to strength, regardless of coating or nitrogen content. Joellenbeck[37] also points out that the impact fatigue value of a weld that would be classified as brittle by the single-blow test may be as high as a ductile weld. Here, too, there is lack of agreement for Rolfe's[38] tests definitely show that the results of the Stanton Repeated Impact machine on welds are similar to those of the Izod. On the other hand, there is no relation whatever between the results of the Schenck machine, using a specimen with a large-radius notch, and the values given by the single-blow Charpy impact test using notched or unnotched specimens. Thum[39] has applied the repeated-impact test to unnotched specimens of welded joints. But, strictly, this is a topic in fatigue.

A tensile-impact test of strap joints—in reality, an impact-shear test—has been used by Jurczyk,[27] and an impact shear test based on the principle of the paper cutter has been suggested by Couzin.[40] In view of the extraordinary difficulty in standardizing the well-known single-blow, notch-impact test, it is hardly to be expected that the tensile impact, impact fatigue and other proposed laboratory impact tests of whose characteristics comparatively little is known at present, will soon become prominent.

Correlations with Other Tests

In order to determine what properties the weld impact test reveals, several attempts have been made to correlate the impact value of welds or weld deposits with the results of tensile, bend, hardness, fatigue, X-ray and service tests on identical materials. As in unwelded material, there appears to be no relation between yield point, tensile strength, yield ratio, energy absorption and hardness, and the results of impact tests. Between impact value and elongation, as well as fatigue limit, there is proportionality in general, as Hoffmann[35] has shown, but the relation is by no means exact and sometimes fails to hold. The exceedingly complicated nature of the relation between impact value and reduction of area even for unwelded material is emphasized by the results of Kuntze.[42] The impact fatigue value seems to be closely related to static tensile strength, but is unrelated to the single-blow impact value.

Perhaps the most significant lack of correlation is between the impact value and the radiograph of a weld. Berthold[43] found that there is a close relation between defects revealed by radiographic examination and all mechanical properties except impact value. As Söhnchen[44] remarks, visible inclusions or blow-holes, being only one reason among many for low impact value, may greatly alter impact value depending largely, however, on their shape and distribution; the standard impact test does not, for example, detect improper fusion along the sides of the V.

The consensus of opinion in favor of the impact test for welds appears to be that the impact test measures a combination of properties embraced in no other single test and is valuable as an indication of the ability of a material to equalize stress concentrations in the vicinity of abrupt changes of section created by sudden application of heavy loads. For example, Schuster, of the British E. B. & E. Insurance Company, strongly advocates the inclusion of the test in specifications for welded boilers. The complaint expressed by some that the scatter of impact results on welds is too large may be an indication that the test distinguishes almost too sensitively between good and bad welds. For it has been clearly demonstrated that uniform impact results are obtained from uniformly good or uniformly bad welds. In the opinion of those to whom the test is superfluous, external factors, such as shape of weld, have more effect on the actual behavior of a joint than internal factors, such as blow-holes, which the test is supposed to detect. In view of the absence of correlation between impact and fatigue values, more success is obtained by eliminating notches or stress-raisers, such as surface cracks and areas of incomplete fusion or penetration, than by raising impact values.

II—Results of Impact Tests of Welds

A brief outline of the uses to which the impact testing of welds has been applied sheds additional light on the significance of the test. The test has been employed (1) to demonstrate the influence of various metallurgical factors on welded joints, (2) to pass judgment on the correct procedure to be employed in welding, and (3) to test the effect of welding on a variety of metals and alloys whether in the form of welding rod or plate to be welded.

Metallurgical Factors

1. Perhaps the greatest utility of the impact test for welds lies in its infallible detection in mild or alloy steels of constituents, such as nitrides, carbides or oxides, that have been in some way deposited in a damaging form within the metal. It was found that the impact value of

arc welds prepared with bare or ineffectively coated electrodes was invariably decreased by 10 to 50% by annealing at about 1550–1700° F., whereas gas welds were improved by such treatment. This effect was shown beyond dispute by the extensive tests of Rolfe[38] and Hopkins,[45] but Zeyen[46] was unable to detect any effect on impact by annealing. The decrease on annealing is more pronounced in low-strength than in high-strength steels. Lohmann,[33] Reeve,[47] and Söhnchen and Kleinefenn[28] have shown that, in all probability, welds containing over 0.025 to 0.05% nitrogen or oxygen, introduced by bare or improperly coated electrodes, will display this peculiar effect, which may be ascribed to precipitation of oxides or acicular nitrides during slow cooling after annealing and is not usually found after rapid cooling as in normalizing. These investigators, and Hensel and Larsen also showed that high nitrogen or oxygen content shifted the "zone of transition" to higher temperatures, and that normalizing shifted the zone to lower temperatures. Besides lowering the impact strength in the usual weld by about 25%, the V. G. B. aging test (7 to 9% stretch in tension followed by ½ hour at 475° F.) displaces the zone of transition from approximately −10° F. to +65° F. The danger involved in subjecting welded or other vessels to a hammer test without subsequently stress-annealing may thus be foreseen, the cold stretching of the V. G. B. test corresponding to the cold work imposed by the hammer test, and the aging treatment simulating conditions during boiler operation.

Kleinefenn[48] has extended the precipitation theory to multiple-layer welds. The normalizing effect of the upper layers on the lower layers of bare wire welds is detrimental to impact properties when the room-temperature solubility content of oxygen is exceeded. No serious loss in impact value was noted by Shepherd and Carpenter[49] in a weld containing 0.03% nitrogen that had been subjected to a variety of aging treatments. According to Wallmann and Pomp,[72] quenching followed by drawing is a more effective treatment than normalizing in raising the impact value of gas or arc welds in low-carbon steel. In gas-free welds the impact value after annealing is dependent on temperature and hence on grain size, as Schuster[8] and others have shown. Annealing temperatures above 1650° F. coarsen the grain size in plate and weld in mild steel and therefore lower the impact resistance. In gas-free, high-strength welds, such as shielded arc welds, annealing just above Ac_3 may raise the impact value at 20° C. by 30%. The relation between gas content and Charpy value has been applied by Meunier[23] to include electrolytic potential and mode of corrosion of welds. Welds with high oxygen and nitrogen contents have high electrode potentials, very low Charpy values and have a tendency to localized corrosion.

At low temperatures, e.g., −70° F., the impact value of silicon-killed mild steel plate of normal grain size is practically nil whereas the extremely fine-grained metal in the weld and adjacent heat-affected zone has a fairly high impact value 20 ft.-lb. Charpy. Hopkins[45] has found, however, that such low-temperature impact strength cannot be depended upon in service. The effect of high and low temperatures has been studied by Söhnchen and Kleinefenn,[28] Lohmann,[33] Aysslinger,[50] Blackwood[51] and Zimmermann.[52] Zimmermann's thorough investigation showed that the "zone of transition" found in mild steel, rolled or cast, is not present in gray, or malleable cast iron, and that the impact value closely followed variations in grain size and initial stresses revealed by X-ray fiber patterns. These investigations and those of Hodge[30] show that the high- and low-temperature impact characteristics of good welds are practically identical with those of parent metal. A minimum in impact value is usually found at 800 to 1000° F., for welds in mild steel; for tough welds the minimum value is usually about 50% of the impact value at 20° C.

Extensive series of tests by Hodge, Rolfe and the British E. B. & E. Insurance Company have shown that the so-called dangerous, coarse-grained junction zone between weld and parent metal has as good impact resistance as the weld or the original plate. Hopkins' micrographs suggest that the junction zone can be made fine-grained throughout with the proper welding technique. However, if the zone is partly or wholly coarse-grained, its sorbitic structure will probably offset to some extent the sensitivity to impact. Besides, in non-aging steels, grain growth is not accompanied by loss of impact resistance. Fry[53] and Beckmann[54] have demonstrated that the martensitic junction zone in austenitic welds in Izett plate has excellent impact properties equivalent to those of tough mild steel. Although in hand and machine flame cutting it might be presumed that the metal adjacent to the cut surface is more rapidly cooled and hence more brittle than the junction zone in welds, Zimmermann[55] as well as Wiss (1909, 1929) and Rambuschek (1925), found, on the contrary, that the machine-cut surface layer has the same impact value as the original structural steel. Hand torch cutting definitely improves the impact value of the surface.

The remarkable improvement in the impact resistance of welded structures, such as pressure vessels, by a stress anneal at about 1200° F. is not reflected to the same extent in Charpy or Izod value. The act of cutting a small specimen from a seam automatically relieves shrinkage and other internal stresses. On this account the high impact value of welds in rigidly clamped or highly stressed plates, found by Daeves, Buchholz and Hochheim, must be interpreted with caution. Prox,[56] Zimmermann[52] and Stiller[57] have found a little improvement in notch impact value by stress annealing. Experience (private communication, H. L. Whitney) in this country has shown that the usual 25 ft.-lb. Charpy obtained in welds in silicon-killed plate is increased to about 29 ft.-lb. or higher after stress annealing at 1200° F.

The fracture of the impact specimen, distributed as it is between cleavage and shear to different extents in different specimens depending upon heat treatment and gas content, is of limited value in detecting improper welding procedure, according to Lefring.[58] For this purpose, however, the nick-break test specified by the American Welding Society is probably more suitable.

Factors Related to Process

2. The impact test has probably been of most service to the welding industry in demonstrating the benefits to be derived from effectively coated welding rods. Tests by a large number of investigators conclusively demonstrate the superior impact resistance of heavily-coated electrodes, particularly of the shielded-arc type. The advance in Izod value from 5 ft.-lb. with bare wire in 1920 to 40 ft.-lb. easily obtained at present with any good quality electrode has been rapid and continuous. Rods for gas welding have not received quite so much attention. Unannealed gas welds generally have not more than 80% of the impact value of the parent metal, carbon arc welds (unprotected) approximately 20 to 40%. But values as high as 100% have been reported[72] in heat-treated, automatic carbon-arc welds made in hydrogen. The low values for gas welds are due to coarse grain, which is sometimes even coarsened by annealing. Water-gas welds, according to Sirovich,[59] may exceed the

parent metal in impact value, and butt resistance welds, as Wuppermann[60] has shown, also have dependable impact properties. The ends of the lap in water-gas welds often show lower values than the middle of the lap or the parent metal.

The impact test has also been used to show the improvements to be derived from multiple-layer welding, reverse runs (tests of arc welds by Swiss Boiler Owners Association, 1921) light top runs and torch annealing. The case for multiple-layer welding is perhaps most clearly stated by Guerrera,[61] who showed that a 2-run arc weld had three times the impact value of a single-run joint, both welds being made with heavily coated electrodes. The larger amount of coarse cast structure in the single-run joint accounted for this difference. Guerrera demonstrated that the continuous band of coarse Widmannstätten structure in the heat-affected zone of the single-run weld was more susceptible to impact fracture than the patches of this undesirable structure that are found in multiple-layer welds. Multiple-layer welding generally gives a further increase of up to 100% in impact value over the two-run weld. But multiple-layer welding does not counteract the brittleness of bare-wire welds. Helin and Svantesson[62] found that multiple-layer welds in which each layer was allowed to cool before the next layer was deposited had about 25% higher impact values than welds in which no time for cooling was allowed. In gas welding the well-known beneficial effect of a reverse run (C. F. Keel), or a light top run on impact value was probably first announced by Buchholz[63]; a reverse run is usually as effective as annealing in increasing the impact value of gas welds by 50 to 100%.

Since impact value responds far more to a change in gas content or grain size than to a change in internal stress, Hoffmann[41] maintains that the high impact value obtained with covered electrodes or certain types of torch annealing is counterbalanced to some extent by the high shrinkage stresses. Peening and also forging of a finished weld, is beneficial to impact value; increases of 10 to 100% have been reported. As plate thickness is increased from $^3/_8$ to $^3/_4$ inch the impact value of all types of welds tends to decrease in comparison with parent metal; the increase in impact value produced by hot forging after welding is greater in the thinner plate. The effect of current strength on impact value, studied among others by Roux,[64] is relatively small although unusually high or low current lowers the impact value. Success with high-current welding was obtained by Ross[22] only with specially fluxed electrodes. The effect on impact resistance of A.C. as compared to D.C., of polarity and of arc length have also received attention (Moon[65]), but no effect of any magnitude was discovered. Within wide limits the quality of a flame cut bevel is without effect on the impact value of the joint. Backhand welding, because it gives rise to less severe overheating, is preferable to fore-hand from the standpoint of impact resistance of welds in steel, according to Hermann[66] and Buchholz,[63] but Hunsicker[67] finds that the reverse appears to be true for welds in copper.

Chemical Composition and Alloying

3. There is little published information dealing with the effect of alloying on impact value of welds in steel. Gas and arc welding rods give somewhat better impact value if the carbon and manganese are on the high side (0.2% C, 1.0% Mn) than if they are on the low side (0.1% C, 0.5% Mn), according to Streb and Kemper.[24] The low impact value of welds made with bare electrodes, usually about 5 ft.-lb., may be increased by 5 to 10 ft.-lb. by addition of 2% Mn or 0.3 Cr, 0.8 Cu, to the electrode. Otherwise, electrode analysis, considering the usual elements, C, Si, Mn, plays a minor rôle in comparison with the composition of the covering. Although plate composition has considerable influence on the impact value of welds below −10° F., Lohmann[38] has shown that it has no influence at +65° F. if covered electrodes are used. Hence, the effect of diffusion of elements from plate to deposit is probably completely masked by other factors. Shielded-arc welds in high-pressure steam piping (0.33% C, 0.75% Mn) and also in castings (0.24% C, 0.6% Mn, 0.8% Mn, 1.2% Ni, 0.4% Mo) develop good impact values at room temperature (30 to 40 ft.-lb. Charpy) and fair values even at 850° F. (16 to 20 ft.-lb. Charpy). Zeyen[46] showed that the impact value of welds rapidly decreased as the carbon content increased up to 0.3% but decreased much less rapidly thereafter up to 0.7% C. Similar observations have been made by the British E. B. & E. Insurance Co., who report a 50% decrease in Izod value as carbon is increased from 0.1 to 0.3%, and who find that in mild steel, sulphur up to 0.12% has no effect on impact properties but that an equal amount of phosphorus has an adverse effect. The small cracks of microscopic dimensions and undesirable microstructure almost always found in the junction zone of welds in steels containing more than 0.3% C probably account for their comparatively low impact resistance.

Söhnchen and Kleinefenn[28] give perhaps the best recent treatment of the subject of alloying although their chief interest is in nitrogen and oxygen content. Nevertheless they state that nickel provides positive protection against mechanical aging. Except in A.C. arc welds, nickel, chromium, vanadium or molybdenum had no effect on the location of the "zone of transition" and had little effect on impact value in general. This experience was reported also by Roš[68] and Sommer.[69] Streb and Kemper, however, obtained excellent impact values for welds in high-strength structural steels using rods containing $3^1/_2$% Ni, 0.15% C or 1% Cr, 0.3% C. In their paper at the I. & S. I. Symposium, 1935, they report high impact values in mild steel and high strength copper steel using rods containing 2 to $3^1/_2$% Ni. Rods containing 0.6% Si gave high tensile impact values (250 ft.-lb.) as welded but were only slightly improved by annealing. (30% increase as compared with over 200% for Mn and Cr-Ni rods.) Hopkins and McAllister[70] also find good impact values for nickel steels (15 ft.-lb. Charpy at −70° F.). Hatfield[71] states that the best impact resistance of the 3% Ni welds is developed only after full annealing or stress annealing. The tensile impact value of high-grade covered electrodes is increased from 500 without nickel to 1400 ft.-lb. with $3^1/_2$% Ni or 0.25% Mo. Hopkins, however, found somewhat better impact properties for the $2^1/_4$% Ni steel (35 ft.-lb. Charpy at 70° F.) than for the $3^1/_2$% Ni (25 ft.-lb. stress-annealed) but both were superior to low-manganese steels (0.25% C, up to 2% Mn (20 ft.-lb. stress-annealed)). The impact value of the nickel steel weld at −75° F. is reduced to about 4 ft.-lb. Charpy by overheating at 1900° F., but the as-welded value of 25 ft.-lb. is restored by heating to 1525° F. for 1 hour. Stress-annealed welds in cast carbon-molybdenum steel (0.3% C, 0.4–0.6% Mo, Crane Valve Steel) give 29.5 ft.-lb. Charpy. Promper and Pohl also report good impact values for welds in rolled molybdenum steel (0.15% C, 0.34% Mo) both at 20 and 500° C. Despite their poor weldability, high-silicon steels (0.15% C, 1.1% Si, 0.9% Mn), according to Grahl,[73] possess good impact properties (30 ft.-lb. Charpy) above 120° F. when flash welded; below 120° F. the zone of transition is encountered and the Charpy value drops below 5 ft.-lb.

Hessler and Kautz[74] and others state that the impact value of welds made in Izett IV steel using the Krupp austenitic electrode (20% Ni, 25% Cr, 0.1% C, 1.5% Mn, 0.75% Si) are remarkably good (60 ft.-lb. DVMR) in all parts of the welds and its vicinity. Although the impact value of welds in 18% Cr iron is low,[41] about 4 ft.-lb. Charpy, an anneal at 1500° F. raises the toughness to 20 ft.-lb. In 18–8 the addition of 1.3% Ta or 0.5% Ti eliminated notch sensitivity in the weld, thus eliminating heat treatment. Arc welds in 18–8, as described by Hessler and Kautz,[97] have excellent impact properties (330 ft.-lb. V. G. B.) though not so high as the unwelded material (525 ft.-lb. V. G. B. unbroken); unless a precipitation inhibitor is added to plate and weld the joint should be water quenched from about 2000° F.

The impact value of non-ferrous welds is a neglected subject. Beyond notes by Brillié[75] on brazing solder, by Hunsicker[67] on copper, and by Bartels[76] and Zimmermann[52] on aluminum and silumin, there has been little published recently on the impact resistance of non-ferrous welds. In his excellent treatise on the temperature variation of impact resistance, Zimmermann showed that acetylene-welded aluminum was more brittle than unwelded aluminum, which could not be ruptured in the impact machine, but that the welds were nearly as resistant to impact at 200° C. as at −200° C. Silumin was much more brittle. Bartels studied the impact fatigue of aluminum, silumin and copper, as well as cast iron and steel. Cast iron, as welded, has about the same impact fatigue resistance (600–1000 blows of the 3 kg. load in the Krupp Repeated Impact Machine) as welds in mild steel; the results on the non-ferrous metals show that the resistance to repeated impact of welds in aluminum and copper is much lower than that of unwelded metal. Hunsicker found that hammering at red heat or annealing at any temperature up to 1000° C. had no effect on the notch-impact value of V and double V welds in copper. Brazing solder, according to Brillié, loses most of its impact resistance after deposition in the joint.

III—Service Tests and Service Results

Service Tests

Impact tests are often performed on Charpy or Izod specimens cut from the welded joints of a completed structure, as described by Czternasty[77] for pressure vessels and by Nápravník and Popov[78] for resistance welded chain. Unfortunately, such specimens, in many cases, do not reproduce the stress conditions existing in the actual joint although service tests have shown that joints of low impact value fail suddenly whereas joints of high impact value fail slowly, cracks propagating only in the highly-stressed area. Unrelieved shrinkage stresses in a welded seam undoubtedly lower its impact resistance although there is no quantitative information on the subject. Interesting applications of an impact testing machine to the testing of full-sized structural elements have been made by Longoni[79] and Roark.[80] Longoni uses the two approximate relations within the elastic limit: (1) that impact stresses in rods of the same length under tension impact are inversely proportional to the square root of the (uniform) cross section, and (2) that the impact stresses in centrally loaded simple beams of the same length are directly proportional to the section modulus. He gives the results of impact tests of welded C-bars of different designs (Fig. 11), which substantiate his conclusions that geometrical shape is the dominant factor in comparing impact resistance of structural elements and that a weld on account of its comparatively small volume, absorbs only a small fraction of the total elastic deformation of a member under impact. Although similarity exists in the elastic region, there is probably no similarity rule for the plastic region. Hence the behavior of large structures under impact cannot accurately be deduced from tests of small models in the ordinary impact machine.

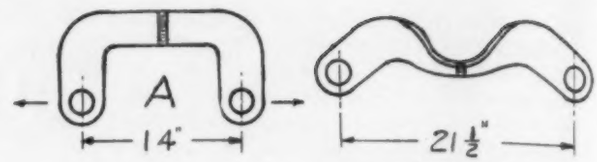


Fig. 11—Butt-Welded C-Bars

Cross Section at Weld	Comparative Strength Static	Impact
Specimen B = 3 In. × ⅝ In.	100%	100% (15 In.-Tons)
" A = 3 In. × ⅝ In.	100%	Over 200% (30 In.-Tons, Unbroken)
" B = 3 In. × 1 In.	266%	About 200%

(Longoni, 1934)

The hammer test, often specified, and fully formulated in the Boiler Code of the Standards Association of Australia, is a variety of service impact test on highly stressed pressure vessels. A typical instance in which the hammer test was successfully applied is described by van Norman[81]; the combined pressure and hammer test revealed only two leaks in the Bouquet Canyon pipe line. If the hammer test is made too severe it may cause permanent, though undetected, damage. According to Shepherd and Carpenter,[49] the hammer or pressure impulse test is used only on relatively unimportant pressure vessels where the cost of an X-ray examination would not be justified.

A sub-zero hammer test for pressure vessels is described by Hopkins.[82] In this test the welded vessel was held for 12 hours at −50° F. under 250 psi pressure. The nickel steel vessel was then removed from the cooling bath for tests; the welded seam withstood hammering along its center as well as on both sides. A test set-up for subjecting welded acetylene generator receivers to explosions is described by Rimarski[83]; the welded receivers were not ruptured even by oxyacetylene explosions that exerted 300 atmospheres pressure. Burkhardt[84] has shown that a welded construction remained unaffected by an under-water explosion that started the seams of a similar riveted construction.

Another service impact test that is often used is the drop-hammer or tup test for welded rail joints. The procedure and results as described by Csilléry,[85] Rietsch and Croskell,[86] the Committee on Welded Rail Joints and Keel[87] show that the number of drops of a heavy ram from a fixed or increasing height which a joint will withstand when supported as a simple beam, is a satisfactory measure of the quality of joint. This test is sometimes used for structural welds, such as bearing joints in bridges and was used by Couzin[40] to show the quality of a welded staircase. Paton[88] and his co-workers have shown that, under repeated heavy impact, welded beams are superior to riveted beams of equivalent static strength. In drop-testing welded demolition bombs the bombs themselves act as the ram. The maximum diameter of the projectile must penetrate at least one foot below the surface of the concrete. Bombs welded according to the A. S. M. E. Code for Class I pressure vessels successfully pass this test. A particularly severe test of welds made according to the Class I Code was

made by the A. O. Smith Corporation who dropped a 1700-lb. skull cracker from a height of about 30 feet on the shielded-arc welded seams of 20-inch pressure pipe under 1000 psi internal pressure and also on a large helium container 7 feet in diameter and under 2000 psi pressure. Tests of welded nickel-chrome armor plate with armor-piercing bullets by the Watertown Arsenal revealed no brittleness even at unusually high impact velocities. That there is nothing inherent in welds to make them sensitive and weak under impact loads is shown by the successful behavior of welds made with bare electrodes as long ago as 1924.[89]

Rail welding rods are evaluated by Keogh[90] by machining Izod specimens from a thick pad deposited on top of the rail. Specimens with notches at critical locations in deposit and junction zone are then tested. Similar tests are described by Bruneteau[91] for welded-on rail overlays. A significant example of the high service impact resistance of welded railway wagons is given by the tests of Ashworth and May[92] for the Victorian Railways, Australia. Racking and buffing tests of unusual severity had no effect on welded wagons but were too much for riveted wagons. Similar results were obtained in tup tests of welded underframes by Metropolitan Cammell's works.

Service Results

Satisfactory results from welded joints have not been confined to the railroads. In the following concluding paragraphs a few especially striking instances are referred to that show the general reliability of welds under impact.

Experience in the last earthquake in the Los Angeles area showed that the most reliable joint for buildings and piping in the earthquake district is the welded joint. According to eye-witnesses at the last 'quake there were no failures of welded pipe joints even in the complicated systems of the oil refineries except under extremely unfavorable circumstances. School buildings in the earthquake areas are now being erected almost exclusively with the aid of welding.

In marine construction welding is now perhaps the chief method of fabrication. On a number of occasions welded ships have been returned to service after severe collisions by merely hammering out dents, as in the case of the Fullagar. Similar experiences have been recorded with a large number of tugs, barges and similar roughly handled craft.[93] A good example of the additional safety involved in the use of welded ships' ventilator fans is shown by Zeriali.[94] No weld failed when a foreign body accidentally passed through the high-speed fan.

Although many all-welded bridges and cranes have been built both in this country and abroad no failure has been recorded. The customary practice in bridge design is to add 30 to 60% to the maximum computed live load stress to take care of the dynamic increment in floor beams, hangers and stringers. There are indications that a fatigue factor will displace this "impact allowance." The capacity for distortion without rupture of a bare-wire fillet-welded mobile crane is shown by Griffin.[95] This heavy-duty crane was severely crumpled in a collision with an overhead bridge; since none of the welds failed the crane was straightened and performed satisfactorily thereafter. Another example of the resistance to impact of welded joints was afforded during the demolition of the Sky-Ride Towers at the Chicago World's Fair.[96] Examination of the distorted structures of aircraft after crashes almost invariably reveals that the welds have not failed.

Welded piping and casing for foundations and pipe lines have withstood a number of severe impact tests. The welded pipe used as piling by the Western Foundation Company of Chicago in the foundations of the Cincinnati Times-Star building received 40 blows of a 5000-lb. hammer followed by aligning without fracture. An unexpected impact test of gas-welded piping occurred when 40 lengths of 16-in. pipe line slid 60 feet down a steep hill when the emergency anchor slipped. Despite buckling and severe distortion in the pipe, there was not a single failure in the welds.

The toughness of welds in 18–8 is shown in some tests by Hessler and Kautz[97] on a 2300-gallon, arc-welded beer tank in V2A (18–8). The tank filled with water, was pushed off a low platform onto an uneven floor; the welds were dented but the tank remained leaktight. After the dents were hammered out the tank was placed in service and performed satisfactorily. They also describe the effects of an accidental explosion in a welded V2A tank; the vessel was severely crumpled but again the welds remained tight.

The Welded Rail Joint Committee[98] of the American Bureau of Welding made a large number of impact and repeated impact tests on various types of street railway joints (about 0.75 carbon) and in all of these investigations the superiority of thermit and resistance welded joints was noticeable as compared with the arc-welded joints using fish plates. A great deal of this superiority was undoubtedly due to the form of the joint, but the results indicated the excellence of the physical properties of welds made by the thermit and resistance butt processes. Many tests of spot welds made by one of the authors in which an attempt was made to break the "spot" with a sledge-hammer, invariably resulted in pulling out a piece of the parent metal.

IV—References and Selected Bibliography*

*In the preparation of this bibliography the authors gratefully acknowledge the assistance rendered by Messrs. G. F. Winterowd and A. W. Lohmann. The complete bibliography with abstracts upon which the review is based is available in the files of the American Welding Society.

[1] D. I. N. Vornorm 1913 March 1934. Specifications for Welding Wire for Gas and Arc Welding; also D. I. N. Vornorm Entwurf DVM-A115.
[2] Önorm B2332, 1934. Austrian Standards Institution. Directions for the Design and Erection of Welded Steel Structures.
[3] Specification of the Joint Commission of Société des Ingénieurs Soudeurs and Institut de Soudure Autogène, 1935. *Rev. Soud. Autog.*, **27**, (257), 2–10, July 1935; also *Le Soudeur-Coupeur*, **10**, 1–8, April 1935.
[4] Rules for Construction and Classification of Steel Ships; also Specifications for Stationary Structures. Le Bureau Veritas, Paris, 1934.
[5] Instructions for the Erection of Arc-Welded Structures and Bridges. Ministry of Public Works, France. *Ann. des. Ponts et Chaussées*, **108**, 303–322, 824–828 (1935).
[6] British Standard Specification No. 538–1934, for Metal Arc Welding as Applied to Steel Structures, March 1934; also No. 639–1935 Covered Electrodes and No. 640–1935 Bare Rod or Wire Electrodes for Metal Arc Welding Wrought Iron and Mild Steel, Dec. 1935.
[7] Standards Association of Australia, Code for Metallic Arc Welding in Steel Buildings. June 1933. No. CA 8–1933.
[8] Schuster, L. W., *Proc. Instn. Mech. Eng.*, **124**, 569–599 (1933).
[9] British E. B. & E. Ins. Co., 1928.
[10] Dustin, H., and Rosenthal, D., Int'l. Assoc. for Testing Materials, Zurich, 1932. I. 409–411.
[11] Bardtke, P., and Matting, A., *Autog. Metallb.*, **26**, 290–293 (1933).
[12] Burns, G., *Metallurgist*, Dec. 1935, 86–88.
[13] Honegger, E., *Schweiz. Verb. Materialprüfung der Technik. Ber.* No. 5, 3–16 (1927).
[14] Mailänder, R., *Stahl u. Eisen*, **55**, 749–754 and 779–786 (1935).
[15] Roberts, A., *Engineering*, **137**, 112–116 (1934).
[16] Dubois, F., *Machines*, July to October 1935.
[17] László, F., *Stahl. u. Eisen* **34**, 1413–1422 and 1521–1525 (1925).
[18] Kleiner, H., and Bossert, K., *Autog. Metallb.*, **27**, 131–139 (1934).
[19] Keel, C. F., *J'l. de la Soudure*, **22**, 12–13, Jan. 1933.
[20] Kautz, K., *Techn. Mitt. Krupp.*, **3**, 143–173 (1935).
[21] Moressée, G., *Rev. Univ. des Mines*, **78**, 345–361 (1935).
[22] Ross, R., *Modern Engr*, **8**, 141–148 and 169–176 (1934).
[23] Meunier, F., *Compt. Rend.*, **196**, 271–273 (1933).
[24] Streb, E., and Kemper, H., *Autog. Metallb.*, **26**, 2–8 (1933); also I. & S. I. Symposium, 1935, II, 573–591.
[25] Warner, W. L., Am. Welding Soc. Jour., **13**, 15–23, June 1934.
[26] McManus, T. K., Am. Welding Soc. Jour., **10**, 16–19, Jan. 1931.
[27] Jurczyk, K., *Elektroschw.*, **5**, 26–33 (1934).
[28] Söhnchen, E., and Kleinefenn, W., *Elektroschw.*, **6**, 181–185 (1935).
[29] Jennings, C. H., Am. Welding Soc. Jour., **9**, 90–104, Sept. 1930. Also Roš, M., and Eichinger, A., *Eidgen Mat. Prüf. Anst. E. T. H. Zurich Ber.*, **86**, March 1935.
[30] Hodge, J. C., Am. Welding Soc. Jour., **13**, 12–17, Jan. 1934.
[31] Rüter, E., *Z. VDI.*, **77**, 917–920 (1933).
[32] Menetrier, A., Am. Welding Soc. Jour., **3**, 13–17, Jan. 1924.
[33] Lohmann, F. W., *Mitt. Forsch.-Inst. Vereinigte Stahlwerke, Dortmund*, **3**, 267–294 (1932–1933).
[34] Bock, E., *Maschinenbau*, **4**, 979–984 (1925). Also *Arcos*, **9**, 697–706 (1932).

[35] Hoffmann, W., *Stahlbau*, **7**, 85–87 (1934).
[36] Fiek, G., *Elektroschw.*, **5**, 67–71 (1934). Also Hoffmann, W., *Elektroschw.*, **5**, 138 (1934).
[37] Joellenbeck, E., and Massmann, C., *Elektroschw.*, **2**, 165–169 (1931).
[38] Rolfe, R. T., I. & S. I. Symposium, 1935, II, 539–552.
[39] Thum, A., and Lipp, T., *Giesserei*, **21**, 41–49, 64–71, 89–95, 131–141 (1934).
[40] Couzin, S., *Jl. S. Afr. Instn. Engrs.*, **30**, 231–249, 320–324 (1932).
[41] Hodge, J. C., *Metal Prog.*, **27**, 33–38, April 1935.
[42] Kuntze, W., *Arch. Eisenhüttenwes.*, **2**, 583–593 (1928–1929).
[43] Berthold, E., *Z. VDI.* **79**, 960 (1935).
[44] Söhnchen, E., *Elektroschw.*, **6**, 155–157 (1935).
[45] Hopkins, R. K., Am. Welding Soc. Jour., **13**, 16–28, Oct. 1934, and **14**, 4–7, March 1935.
[46] Zeyen, K. L., I. & S. I. Symposium, 1935, II, 617–633.
[47] Reeve, L., I. & S. I. Symposium, 1935, II, 517–529.
[48] Kleinefenn, W., *Carnegie Schol. Mem.*, **22**, 97–133 (1933).
[49] Shepherd, T. C. R., and Carpenter, S. W., I. & S. I. Symposium, 1935, II, 161–179.
[50] Aysslinger, H., *Mitt. Forsch. Anst. GHH. Konzerns.*, **2**, 135–140 (1932–1934).
[51] Blackwood, R. R., *Jl. Instn. Engrs. Australia*, **6**, 421–443 (1934).
[52] Zimmermann, F., *Ber. Inst. Mech. Tech. u. Materialkunde, Techn. Hochsch.*, Berlin, 4 (1934).
[53] Fry, A., *Elektroschw.*, **4**, 201–208 (1933).
[54] Beckmann, E., *Techn. Mitt. Krupp*, **3**, 137–142 (1935).
[55] Zimmermann, J. H., *Proc. Intl. Acet. Assn.*, **1934**, 88–99; also Hovey, O. E., Am. Welding Soc. Jour., **10**, 24–25, June 1931.
[56] Prox, W., *Z. VDI.*, **76**, 497–504 (1932).
[57] Stiller, E., *Elektroschw.*, **5**, 230–232 (1934).
[58] Lefring, N., *Forshungsarbeiten VDI.* No. **332** (1930).
[59] Sirovich, G., *Met. Ital.*, **25**, 502–524, 569–598, 653–672, 725–740, 799–824 (1933).
[60] Wuppermann, T., *Z. VDI.*, **73**, 1758–1763 (1929).
[61] Guerrera, U., I. & S. I. Symposium, 1935, II, 277–279.
[62] Helin, E., and Svantesson, S., I. & S. I. Symposium, 1935, II, 373–390.
[63] Buchholz, R., *Autog. Metallb.*, **24**, 288 (1931).
[64] Roux, A., *Technique Moderne*, **19**, 105–110 (1927).
[65] Moon, A. R., *Jl. Instn. Engrs. Australia*, **2**, 258 (1930).
[66] Hermann, F., *Autog. Metallb.*, **26**, 145–150 (1933).
[67] Hunsicker, L., *Autog. Metallb.*, **28**, 275–282, 289–297 (1935).
[68] Roš, M., *Schweiz. Verb. Materialprüfung der Technik. Ber.* No. **5**, 17–59 (1927).
[69] Sommer, F., *Autog. Metallb.*, **26**, 22–27 (1933).
[70] McAllister, L. P., *Welding Engr.*, **20**, 30–32, May 1935.
[71] Hatfield, W. H., I. & S. I. Symposium, 1935, II, 363–371.
[72] Wallmann, K., and Pomp, A., *Mitt. KWI. Eisenforsch.*, **14**, 271–294(1932).
[73] Grahl, H., *Arch. Eisenhüttenwes.*, **4**, 593–600 (1931).
[74] Hessler, R., and Kautz, K., *Wärme*, **58**, 511–519 (1935).
[75] Brillié, J., *Le Soudeur-Coupeur*, **14**, 1–4, Nov. 1935.
[76] Bartels, B., *Ber. Inst. Mech. Tech. u. Materialkunde, Techn. Hochsch.*, Berlin, 3 (1930).
[77] Czternasty, G., *Z. VDI.*, **76**, 679–682 (1932).
[78] Nápravník, V., and Popov, S., I. & S. I. Symposium, 1935, I, 513–526.
[79] Longoni, A. J., *Modern Engr.*, **8**, 188–193, 212–215, 231 (1934).
[80] Roark, R. J., Am. Welding Soc. Jour., **7**, 57–64, Feb. 1928.
[81] van Norman, H. A., *Civil Engg.*, **4**, 306–310 (1934).
[82] Hopkins, R. K., *Metals Technology*, **2**, Aug. 1935.
[83] Rimarski, W., and Friedrich,—., *Autog. Metallb.*, **26**, 49–54 (1933).
[84] Burkhardt, —., *Elektroschw.*, **3**, 189 (1932).
[85] Csilléry, D., *Elektroschw.*, **6**, 25–33 (1935).
[86] Rietsch, E., and Croskell, A. C., I. & S. I. Symposium, 1935, I, 339–347.
[87] Keel, C. F., *Jl. de la Soudure*, **22**, 88–98, April 1932. Also Reiter, M., *Org. Fortschr. Eisenbahnwes.*, **85**, 1930, 419–432.
[88] Paton, E. O., and Diatlov, A. V., Am. Welding Soc. Jour., **10**, 39–43, June 1931.
[89] Goldmark, H., Spraragen, W., and Warner, W. L., Am. Welding Soc. Jour., **3**, 27–69, Oct. 1924.
[90] Keogh, C. P., *Modern Engr.*, **8**, 220–225, 242–247 (1934).
[91] Bruneteau, M., *Rev. Soud. Autog.*, **26**, 8–12, Sept. 1934.
[92] Ashworth, J. M., and May, H. N., I. & S. I. Symposium, 1935, I, 299–306.
[93] *Trans. Soc. Naval Arch. & Marine Engrs.*, **42**, 232 (1934).
[94] Zeriali, G., I. & S. I. Symposium, 1935, I, 609–618.
[95] Griffin, R. G., I. & S. I. Symposium, 1935, I, 565–571.
[96] Wilson, A. L., *Welding Engr.*, **20**, 24–27, July 1935.
[97] Hessler, R., and Kautz, K., *Elektroschw.*, **5**, 81–88 (1934).
[98] Committee on Welded Rail Joints Final Report, New York, Sept. 1932.

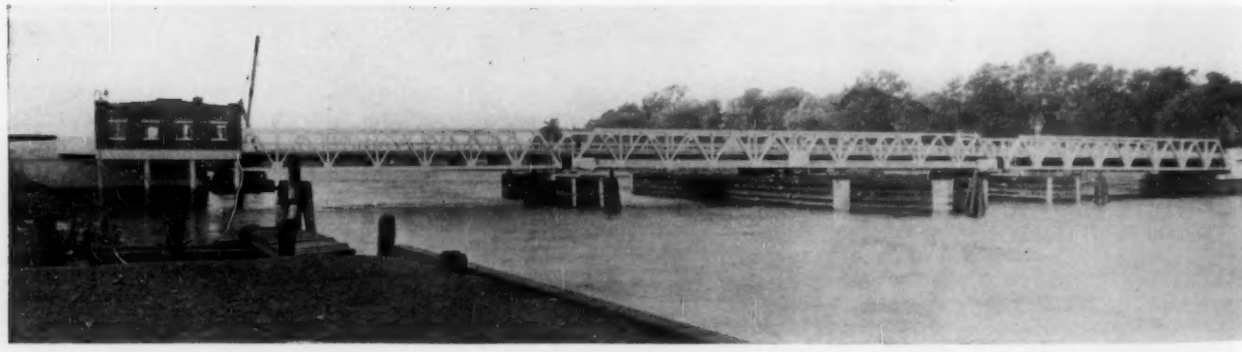


Fig. 1—General Side View of Bridge

Welded Highway Bridge, Burlington County, New Jersey

By W. K. GREENE* AND C. W. WIXOM*

THE highway bridge recently built over Rancocos Creek between Riverside and Delanco, Burlington County, New Jersey, has several features which are of interest as pertaining to welded construction. Noteworthy are the following: The choice of truss sections for simplicity of welding details; the treatment of the floorbeam connections to the trusses with reference to floorbeam deflection; support of the pony truss compression chords and connection of the sidewalk brackets; and the provisions made to facilitate the work of the erector in the field.

* Assistant Engineers, American Bridge Company.

General Description

This bridge, which is of notable size for a welded structure, is made up of three pony truss spans; a swing span 160 feet center to center of end wedges, flanked by two fixed approach spans each 112 feet 8 inches center to center of end bearings. Provision is made for both vehicular and pedestrian traffic. The roadway is 36 feet wide and one walk, 4 feet wide, is supported on cantilever brackets outside the downstream trusses. The work is all welded with the exception of the loading girder and machinery supports of

Fig. 2—General End View of Bridge

the swing span, which are of the conventional riveted construction. Figure 3 shows a general plan and elevation of the structure and Table 1 gives the sections of the members.

Design

The design is in accordance with A. A. S. H. O. Specifications, H 20 loading, except for the welding and minor modifications. O. E. Hovey's Specifications were used for the machinery design and also for the stress combinations on the swing span.

Carnegie beams were used throughout for the trusses and sections with depths of about 14 inches were selected for all members. The sections used for the heavier

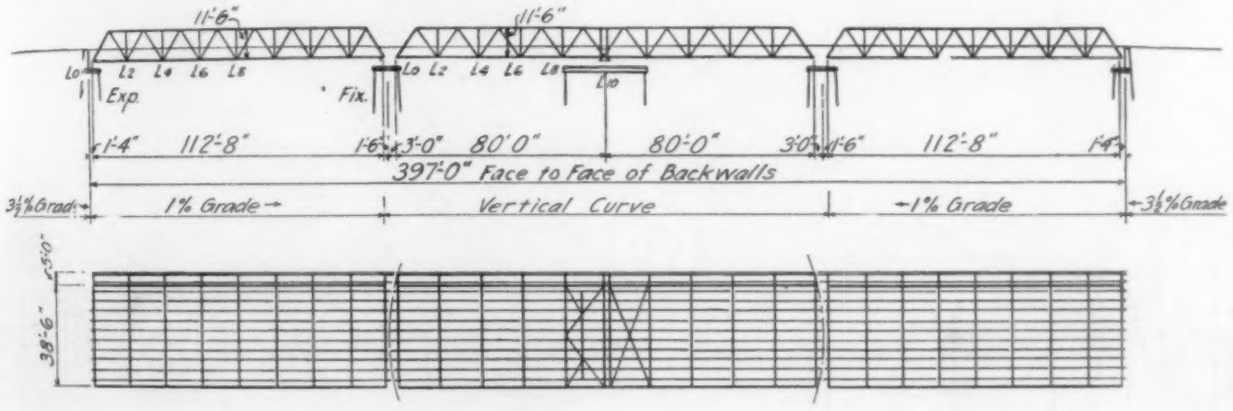


Fig. 3 General Plan and Elevation.

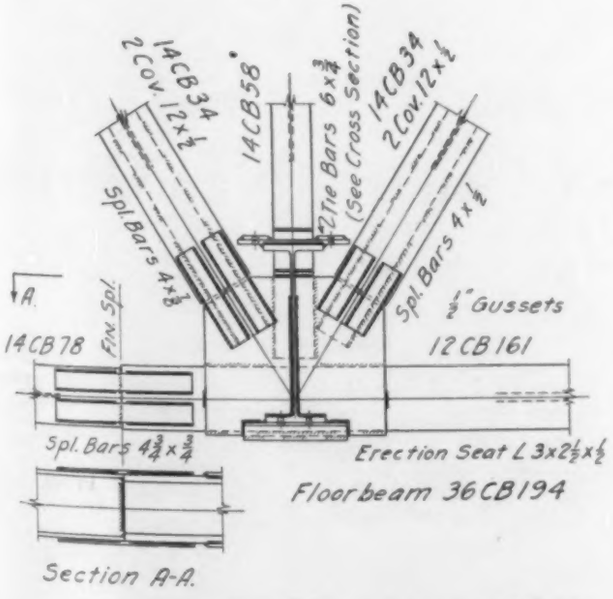


Fig. 4 Joint L2 - Fixed Span.

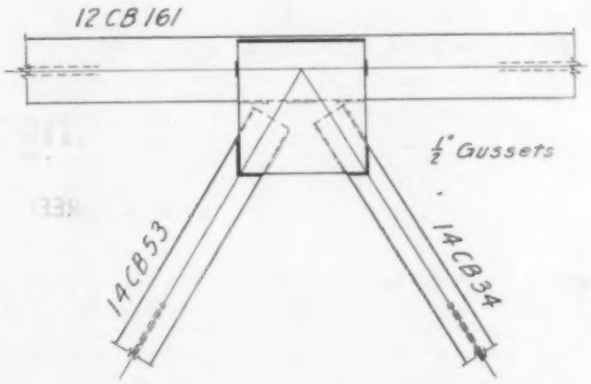


Fig. 5 Joint U5 - Fixed Span.

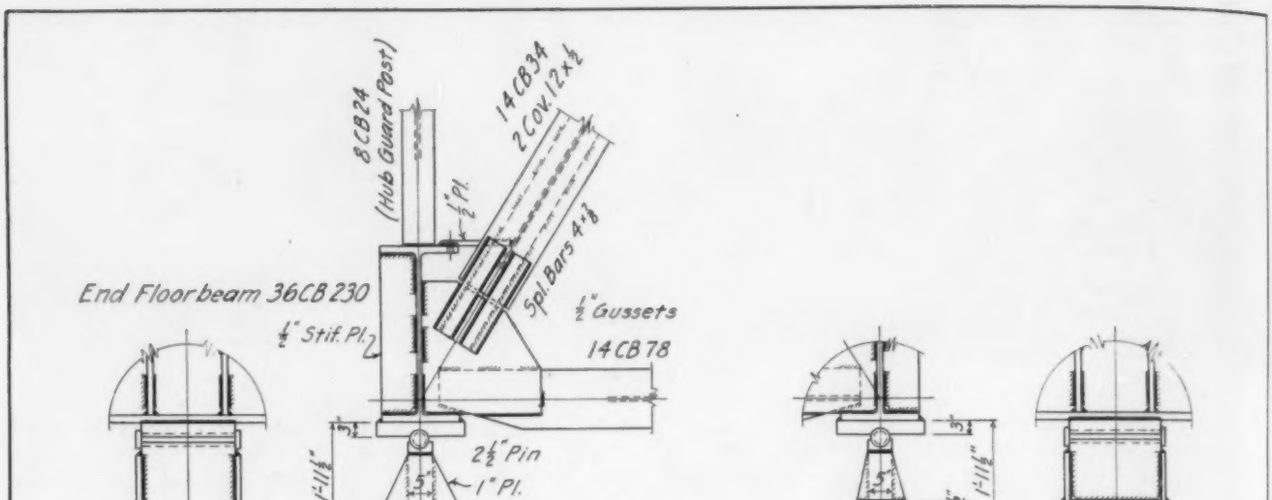


Fig. 6 Joint Lo & Shoes - Fixed Span.

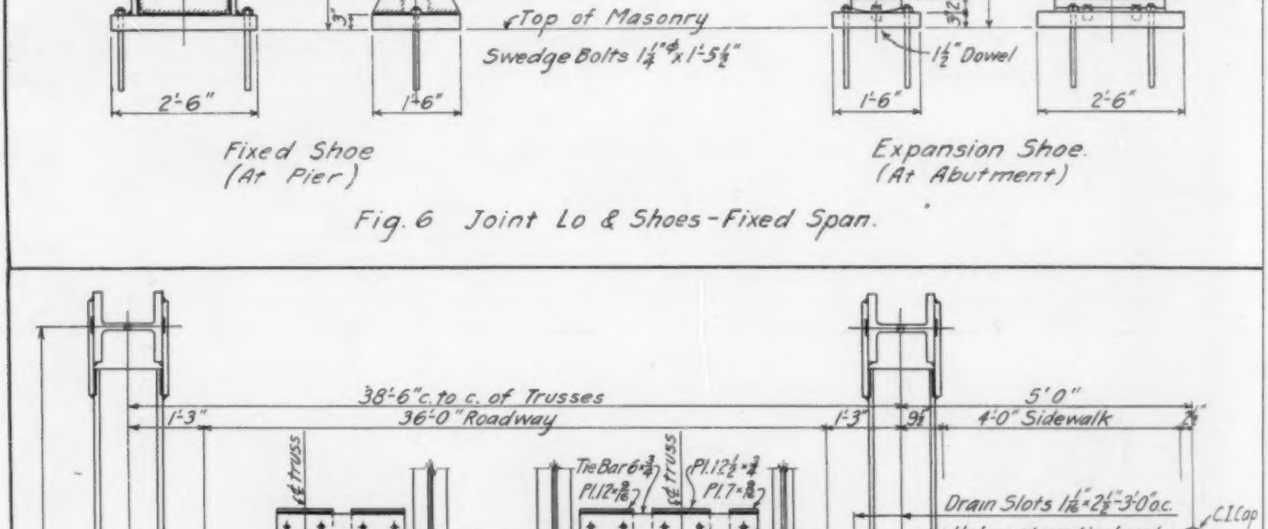


Fig. 7 Cross Section.

chord members are nominally 12 inches deep, but the actual depths are about 14 inches. The heavier diagonals required more area than was available in a convenient size of Carnegie beam, and the additional area was obtained by the use of cover plates on the flanges. These cover plates are all $^1/_2$ inch thick (which is the same thickness as the gusset plates), of the required width, and tacked to the Carnegie beams by 3-inch welds spaced 8 inches centers. The cover plates are connected to the gussets with outside splice bars as shown in Figs. 4 and 10. This detail simplified the truss joints and at the same time served to diminish the size of gusset plates and the length of the welded connections. Figure 5 shows a typical joint for members

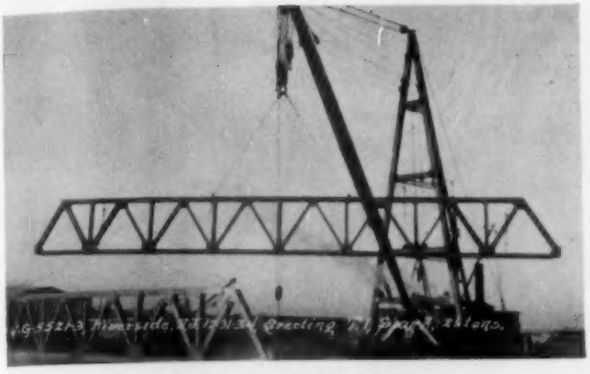


Fig. 8—Erection of Fixed Span Truss

not requiring cover plates. Carnegie beams were also used for the floorbeams and stringers.

Fillet welds were used almost exclusively in the shop and field. All welds taking calculated stress are $^3/_8$-inch fillets, with the exception of those for the shoes and the floorbeam connections to the trusses which are $^1/_2$-inch fillets. The welds for the hub guard, railing and a few minor connections are $^1/_4$-inch fillets. A unit stress of 3000 pounds per linear inch of $^3/_8$-inch fillet was used, applied to the combined stresses.

As all spans of this structure are of pony truss construction, it was necessary to have rigid connections between the floorbeams and trusses in order to provide adequate lateral support for the compression chords. The effect of the floorbeam deflection on these connections was also considered. The required rigidity was provided by connecting the top and bottom flanges of the floorbeams to the trusses, as shown in Figs. 4 and 7. Further, to guard against overstress as a result of floorbeam deflection, the shear connections were confined to the lower two-thirds of the floorbeam depths. Figure 7 also shows the cantilever sidewalk brackets. The bars which connect the top flange of the floorbeams to the trusses were extended to form the tension ties for these brackets.

Holes $1^1/_{16}$ by $2^1/_2$ inches spaced 3 feet centers were provided in the top and bottom chords and hub guards for drainage.

Figure 6 shows the slab type of fixed and expansion shoes which were used for the fixed spans.

The roadway floor on the approach spans is a $6^1/_2$-inch reinforced concrete slab, but on the swing span a $3^1/_2$-inch armored type floor filled with concrete was used to reduce the swinging load. On account of the great stiffness provided by both the reinforced concrete slab and the armored floor, no lateral bracing was used except in the center panels of the swing span where diagonals were provided to take care of stresses from the turning machinery.

The swing span, which is of the center bearing type, may be operated either electrically or by hand. The machinery is of simple design and employs five speed reducers with totally enclosed gears running in oil baths. The motors used for electric operation are 15 hp. for turning and $7^1/_2$ hp. for the wedges.

In order to balance the swing span a concrete counterweight was placed in the bottom chord on the side opposite to the sidewalk.

Erection

This structure was built without the use of any temporary falsework and the details were so arranged that all steelwork could be erected prior to the start of field welding.

The approach span trusses, which are 114 feet long by 13 feet deep and weigh 26 tons each, were completely welded in the shop and shipped to the field ready to be set in place. Figure 8 shows one of these trusses being erected by a derrick boat. The swing span was erected in the open position to avoid interrupting navigation, and the fender piles around the center pier were used as falsework. The trusses for the latter span were welded into three units each in the shop and assembled on the fender with the remainder of the swing span steelwork.

In order to facilitate the field work and insure accurate alignment, the chords of the swing span trusses and all floorbeams were milled to exact length. Erection seats, sufficiently strong to take the dead load of the steelwork, were placed under each floorbeam. Holes for erection bolts were provided in these erection seats and also in the tie bar connections at the tops of the floorbeams. These provisions enabled the erector to assemble complete all the steelwork in the structure in final position before starting the field welding. Figure 9 shows one of the fixed spans ready for welding.

All steelwork was given one coat of paint in the shop, with the exception of the areas to be field welded, which were coated with linseed oil. Two coats of paint were applied in the field after the welding was completed.

Welding Data

The total weight of structural steel in this bridge is 470 tons.

Electric motor driven direct current welding machines of 300 and 400 ampere capacity were used for the shop welding. The field welding was done with gasoline engine driven direct current welding machines of 300 ampere capacity. The current used varied from 175 to 250 amperes.

Fig. 9—View of Fixed Span Ready for Welding

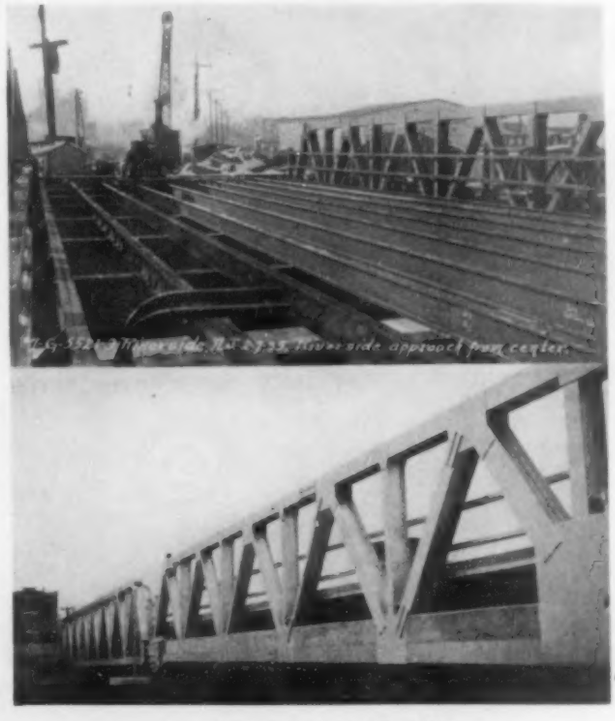


Fig. 10—Close-Up View of Truss Joints

Table 1—Sections of Members

Fixed Spans Member	Section	Swing Span Member	Section
L0–U1	14 CB 34 2 Plates 12 x 1/2	L0–U1	14 CB 84
U1–U3	14 CB 78	U1–U7	14 CB 84
U3–U9	12 CB 161	U7–U10	12 CB 190
L0–L2	14 CB 78	L0–L6	14 CB 84
L2–L8	12 CB 161	L6–L10	12 CB 190
U1–L2	14 CB 34 2 Plates 12 x 1/2	U1–L2	14 CB 38
L2–U3	14 CB 34 2 Plates 12 x 1/2	L2–U3	14 CB 38
U3–L4	14 CB 34 2 Plates 5 x 1/2	U3–L4	14 CB 42
L4–U5	14 CB 53	L4–U5	14 CB 42
U5–L6	14 CB 34	U5–L6	14 CB 58
U6–L7	14 CB 34	L6–U7	14 CB 42 2 Plates 5 x 1/2
U7–L8	14 CB 34	U7–L8	14 CB 42 2 Plates 12 x 1/2
Verticals	14 CB 58	L8–U9	14 CB 42 2 Plates 12 x 1/2
		U9–L10	14 CB 42 2 Plates 16 x 1/2
		L10–U10	2–14 CB 74
		Other verticals	14 CB 58
Intermediate floorbeams	36 CB 194	Intermediate floorbeams	36 CB 194
End floorbeams	36 CB 230	End floorbeams	36 CB 230
Roadway stringers	14 CB 38	Roadway stringers	14 CB 42
Sidewalk stringers	12 CB 16.5 12 [20.7	Sidewalk stringers	12 CB 16.5 12 [20.7

Loading girder: 2 Web Pls. 48 x 5/8, 8 Angles 8 x 8 x 1, 12 Cov. Pls. 18 x 13/16

The welding in both shop and field was done with electrodes of the shielded arc type. Electrode sizes 1/8 inch, 5/32 inch, 3/16 inch and 1/4 inch were used.

A total of 10,200 linear feet of equivalent 3/8-inch fillet was placed, divided as follows: shop weld 7000 feet or 14.9 feet per ton of steelwork; field weld 3200 feet or 6.8 feet per ton of steelwork. These quantities do not include the welding for the armored type floor on the swing span, nor is any compensation made for that part of the steelwork which is of riveted construction.

The Kolyn Construction Company, of Trenton, New Jersey, had the general contract for the entire project. The Consulting Engineers were the Bridgeweld Engineering Company and Ash, Howard, Needles and Tammen, of New York City. The American Bridge Company detailed, fabricated and erected the steelwork and machinery. All field welding was done by the J. K. Welding Company, of New York City.

Fusion Welding of Bridges*

By P. G. LANG, Jr.†

Specifications

As a process for joining metal parts, welding has, within the past decade, entered the structural field, and continues to win for itself a growing measure of recognition. The advantages claimed for this procedure include economy of material without sacrifice of safety, simplicity of design with enhanced aesthetic possibilities, economy of space, absence of objectionable noises incident to the prosecution of the work and minimization of traffic complications during repairs or alterations to highway or railway bridges.

In all discussions of bridge welding an essential assumption is that the bridge concerned has been properly and completely designed, in accordance with the most modern and approved specifications. The most recent specifications available to the American engineer at this writing, and those recommended for use in this phase of the work, are the following:

For Highway Bridges—The American Association of State Highway Officials "Standard Specifications for Highway Bridges—1935."

For Railway Bridges—American Railway Engineering Association "Specifications for the Design and Construction of Steel Railway Bridges and Concrete Railway Structures—1935."

Bridge design is fully covered in the specifications named for the respective classes of bridges concerned. Each class of material contemplated for use by the foregoing specifications is, in the majority of cases, covered by an appropriate specification of the American Society for Testing Materials.

Detail of the welding procedure and accessories is set forth in the AMERICAN WELDING SOCIETY "Specifications for Design, Construction, Alteration and Repair of Highway and Railway Bridges by Fusion Welding—1936." The recommended use of this specification presupposes the proper application of the general bridge specifications herein cited, and the welding specification is designed to govern solely those phases of the work which are inseparably associated with welding as a distinct articulative process.

The specification of the AMERICAN WELDING SOCIETY is divided into sections, covering, respectively, the following:

General Provisions
Design of New Bridges
Strengthening and Repairing of Existing Bridges
Filler Metal
Equipment and Processes
Workmanship
Technique of Arc Welding
Technique of Gas Welding and Gas Cutting
Inspection

The AMERICAN WELDING SOCIETY Specifications also contains a "Foreword" and "Appendix," both of which embody information of the highest value to the designer and welder, and essential to a complete understanding of its other sections.

On all welded bridgework it is essential that precautions be taken to insure a homogeneous blend and absolute bond between the base and deposited metals. The indications are that ordinary structural steel, made in accordance with current specifications, which limit the carbon content to 0.25% maximum and the manganese content to 1.00% maximum, is satisfactory for such work. Steel of this character is a product of modern furnaces, which is obtainable without difficulty.

The quest of an agency to enhance the corrosive-resistant properties of structural steel has, within recent years, led to the extensive use of steel containing a copper ingredient of approximately 0.20%. Experience indicates that the presence of copper in this and even considerably greater quantity has no tendency to disqualify the material for use in welded structures. The so-called high-tensile structural steels, containing carbon in excess of 0.25%, silicon, nickel, etc., are not readily adaptable to welded work, and require the use of special materials and processes, which represent deviations from standard practice, and involve additional cost elements.

* This material was originally prepared to form the Bridge chapter of the proposed A. W. S. Handbook. Discussion and criticism by members of the Society are invited.

† Engineer of Bridges, The Baltimore and Ohio Railroad, Baltimore, Md.

Where welding is adopted for the repair or strengthening of an existing bridge, the characteristics of the metal in the structure should be ascertained, and its adaptability to welded work determined. On the basis of information thus acquired the type of electrode and new weld metal best suited to the conditions should be selected.

Design

Within the duties of the bridge designer fall the preparation of general and detail plans, the economic analysis of the project and a forecast of the procedure. To realize the maximum benefits from structural welding, and avoid the difficulties which have, in the past, attended some projects of this character, it is essential that the use of welded connections receive, from the initial stages of the work, due cognizance in the design.

The economic aspect of structural welding has been the subject of much discussion in the recent past, and, at least so far as the American field is concerned, remains somewhat vague and indeterminate. A large and valuable mass of literature on this topic has originated in lands where material prices are relatively high and labor rates low in comparison with American standards. In its economic phase the subject has been characterized by a marked trend toward generalities, originating possibly in the relative ease of acquiring facilities and equipment for the smaller welding projects. However, the expense and difficulty of assembling a suitably-qualified personnel and the actual field costs of prosecuting work of this character under varying conditions constitute elements which require careful investigation for each case considered.

Structural welding, in its relation to metallic bridgework, generally concerns both highway and railway bridges of ordinary current types; that is, it relates primarily to the smaller structures. There is, in general, no question concerning the physical possibility of welding any metallic structure whatsoever, either in shop or field. However, the wisdom of such procedure from an economic standpoint represents a different phase of the matter, a rigid analysis of which should decide the choice. Even at this day, instances occur on minor repair projects where the driving of rivets by hand is more economical than the use of pneumatic appliances. Thus resort to an innovation does not invariably represent economic advantage.

For application to bridgework, welding most strongly recommends itself to the engineer on projects which represent the following conditions:

(*a*) Highway bridge repair projects.
(*b*) Railway bridge repair projects
(*c*) Metallic bridge projects in thickly-populated metropolitan areas, where the absence of objectionable noises is desirable.

For riveted bridges an adequate and proper design must necessarily show the character of each connection and the location of each rivet. In the design of a welded structure should appear the location and character of each weld. While this observation applies with obvious force to a new bridge, the principle extends to repair projects, where each detail should be carefully developed, and made a matter of plan-record before arrangements are concluded for the actual prosecution of the field work. Also, in connection with bridge repair or reinforcement projects, it is essential that the preliminary studies include a careful investigation of the bridge from the standpoint of carrying capacity, and an accurate forecast of the quantity, disposition and character of new material to be applied. It is essential that the sequence of welding be carefully determined in advance, and shown on the plans. This phase of the designer's work is perhaps its most important, and constitutes an indispensable part of the design-plan.

Experience in the construction of welded bridges has been generally deemed to establish the maxim that shop welding is more economical and less difficult than similar work performed in the field. This has received a degree of assent which justifies an effort on the part of the designer to hold field welds to the minimum consistent with proper design and with the limitations imposed by shop and transportation facilities.

With a general line of demarcation established between shop and field welds, the designer of a welded structure is confronted with the problem of determining that arrangement of welded connections, both in the shop and field, which will be most favorable for carrying out the work. Incident to this phase of the design, the ends to be sought in the disposition of jointures include accessibility, maximum use of flat, horizontal and vertical welds, in the order cited, holding overhead welds to the minimum, uniform thickness of material at jointures, and use of long, thin, in preference to short, thick welds.

The general rules which govern the design of metal bridges having riveted or bolted connections apply to similar structures in which welded connections are to be used. Thus, in riveted design, it is recognized that the floor of a bridge participates in the chord stress, and the stringer connection angles, if thin, and with connection rivets close to the root of the angle, have a tendency to crack in the root. In the case of riveted work this evil is overcome by spacing the rivets widely, and thus affording the angle a yield-margin, by which its participation in the chord stress is alleviated. With the welded connection a similar condition demands cognizance, and may be solved by a corresponding arrangement of welds.

A tendency of design which is altogether too frequent with riveted connections, and becomes accentuated with the introduction of the welded joint of the rigid type, arises from the fact that the actual bending moments in columns tend to exceed drafting room assumptions, with the consequence that the design provides inadequate strength for the columns and excessive strength for the beams. In order to conform to the rules of economic design, and obtain the maximum advantages from the use of welded connections, it seems necessary, in many cases, to substantially revise the assumptions for beams and columns to meet the conditions cited. In this and other problems of structural welding, engineers and designers should be able to advantageously capitalize experience acquired in connection with other designs, since a welded metal structure, especially one with rigid connections, presents many points of analogy with monolithic construction.

Peculiarly associated with the use of welded connections is the problem of the internal or so-called "locked-up" stresses produced by the high temperatures incident to the process. While expansion and contraction in response to thermal fluctuations are inevitable in any metallic body, stress of the character now under consideration, which arises from the inhibition of the normal adjustive tendency, may be aggravated by extreme thickness of metal in the members connected, and restraint of normal deformation which should respond to thermal changes in the welded structure.

While, in some recorded cases, these stresses have been of sufficient intensity to produce fracture prior to the application of the live-load, their most insidious and perilous phase is that in which their presence is not immediately obvious, but where they are of sufficient magnitude

to cause failure upon the application of live-load. At every stage of the work, in designing room, shop and field, this factor requires careful study. Procedure for the relief of locked-up stresses consists primarily of resort to annealing. This process has not yet attained a stage of development which renders its satisfactory performance in the field a possibility. However, the equipment of shops designed for the prosecution of welded bridgework must necessarily include annealing facilities for the accomplishment of this end.

With the object of minimizing locked-up stress, the plans should be developed along the lines of permitting the maximum freedom of movement incident to fabrication, assembly and erection. In view of the general resort to annealing as a measure of stress-relief, especially at critical points in the structure, any joints designed for annealing should be definitely identified on the drawings. At some points, where other stress conditions permit, the use of flexible joints affords a degree of relief.

An essential difference between the highway and railway bridge is that, in the highway structure, the dead load generally represents the major portion of the load to be considered, whereas in the railway structure the dead load comprises a relatively small proportion of the total forces for which the bridge is to be designed. Another characteristic of railway structures is the severity of impact.

While reversal of stress occurs in all bridges, both highway and railway, this factor operates with peculiar severity on structures of the latter character. The constant passage of rolling loads and the forces originated thereby distinguish the service requirements of bridges from those of structures of any other character, and have a very direct bearing on railway bridge design. These recurrent alternations of force tend to create and develop within the metallic sections composing the structure the condition known as "fatigue," ultimately producing extreme fragility, which, if not observed and corrected, may lead to unsatisfactory results.

The most superficial perusal of any standard bridge specification will indicate to the reader that such forces are recognized and due allowance for the same is a routine part of the designer's work. The introduction of the welded joint, especially of the rigid type, bestows added importance on this subject, since forces within the structure, whether from live load, dead load or impact, operate with direct and unabated rigor upon the connections, whose ability to properly withstand such stresses is an essential condition to the stability of the bridge.

The problem in this case is dual in character, relating to the design and location of the joint and to the character of metal of which it is composed. While, from both standpoints, the field is open to extensive research, experience already acquired appears to indicate that the maximum attainable continuity and uniformity of section is desirable along the line of stress-travel, that sharp changes of direction in the line of stress-travel should be avoided, and the details formulated on the basis of making such deviations as gradual as possible. Experiments indicate that butt welds offer the maximum resistance to fatigue.

Within the category of stress-alleviation expedients consideration may be given to joints of the flexible type. In welded work such a joint is formed by the use of angle cleats, and welding is applied to the outer edges of the angle, which thus has a bend-freedom at least equaling that which would be afforded by a bolted or riveted connection. Thus the introduction of the welded joint opens to the designer of welded bridges extensive latitude in the use of standard steel design methods. Since the rigid welded connection is unyielding to a degree which approaches absolute continuity, such connections receive the full and direct effect of secondary or bending stress, which must be given due consideration in the design.

The corrosion-resistant property of weld metal is a matter on which very meager data have been assembled. This deficiency is due principally to the relatively short period which has elapsed since the introduction of structural welding, and the absence of service data. Definite determination of this point must await the lessons of research and experience.

The modern shop for the production of riveted work represents the contemporary stage of an evolutionary process which has followed the trend of development and improvement. Thus the shop for welded work must undergo a similar process of change and betterment, reflecting the progress of the art and the accumulations of knowledge. On the basis of the known requirements of welded work, it is possible to deduce certain essential distinctions which must exist between the equipment of a shop designed to perform fabrication in this manner and one devoted solely to riveted or bolted work.

Since the economic advantage of shop welding over that performed in the field has general acceptance, the tendency of the welding fabricant will be to carry out the maximum work before shipment. Hence a welding shop will be required to handle large members and sections. Since the design tendency is to provide a maximum of flat welding, it will be necessary to readily place members and sections in the varying positions which will best facilitate the prosecution of the work in this manner. To meet these conditions the facilities of a modern welding shop must necessarily be adapted.

Since annealing appears to afford the best means of relieving the condition of "locked-up" or internal stress resulting from the high temperature incident to the welding process, it is desirable that the equipment of a bridge-welding shop include furnaces into which it is possible to place for annealing large assembly pieces, with accessories for the expeditious and economic handling of such material.

In the conduct of the field work, the operative welder should adhere strictly to the plans as to the sequence, form and disposition of welds, and other details of material and procedure formulated incident to the preparation of the design. Especially the size of joints indicated on the drawings should, in no case, be exceeded in actual construction.

Since rigid adherence to the plans requires the welder's undivided attention, it is necessary that the operative personnel be insured reasonable comfort in the prosecution of its work, and that, where necessary, men and equipment be protected against the inclemencies of the weather. Some discussion has occurred concerning the weather and temperature conditions which render the prosecution of field welding impossible or inexpedient. While, with respect to the technique and materials employed, this phase of the question remains indeterminate, it would seem that its bearing on the working personnel should be admitted as the main element in the solution, since it is obviously impossible for a worker subjected to physical discomfort to properly carry out an intricate and delicate task. Accordingly, when conditions become such as to preclude the prosecution of the work in reasonable physical comfort, it appears the part of wisdom to discontinue operations pending the advent of more favorable conditions.

Electrodes

The character of the electrode is of major importance in structural welding. Experience and research in the

United States and other lands indicate that electrode rods coated with chemically-inert substances are decidedly preferable to bare rods. By the use of rods thus coated the incandescent metal is afforded the maximum protection against impairment through chemical interaction with atmospheric elements, and the deposited metal, when cooled, possesses the desired characteristics of ultimate strength, yield point, elongation, reduction of area, etc.; that is, by the use of coated rods it is possible to control the quality and character of the weld metal, and to conform its chemical and physical properties to those of the base metal.

With electrodes of the covered type the most satisfactory results are obtained by reversal of polarity or the use of alternating current.

Since the deposited metal from a coated rod acquires a relatively high degree of fluidity, and its cooling period is extended, the layers thus deposited do not ordinarily attain the thickness of those resulting from the use of bare rods. In view of the protection from atmospheric agencies, covered electrodes may be used with longer arc and correspondingly higher voltage current than bare electrodes, although permissible heating of the base metal and flow of the weld metal impose limitations upon both arc length and current.

Qualifications

Bridges do not partake of the character of a mass-product. Each bridge is designed to meet peculiar conditions, and becomes a specific entity, representing a comparatively large monetary investment, closely associated with public welfare and safety. Each connection loses its identity as an individual object, but acquires importance as an essential part of a whole, to whose stability and permanence its own is vitally related. For the bridge in its entirety, and for its individual connections, it is impossible to produce samples and test to destruction. This collective aspect renders it vitally essential that design, materials, processes and personnel associated with the construction of bridges be scrutinized with peculiar care, not only at the beginning of the work, but throughout its progress, to insure that each element represents the highest attainable quality and the most approved standards.

The character of the personnel, both supervisory and operative, charged with the carrying out of a welding project is of as immediate and obvious importance as the excellence of design and workmanship. Each member of the personnel, certainly in its supervisory branches and preferably throughout the entire organization, should be familiar with metallic bridgework in all of its phases, and should, in addition, possess an expert knowledge of welding accessories and procedure. The engineer to whom such a project is assigned should be vested with complete authority and must assume full responsibility.

Since it is unlikely that, in the majority of cases, the engineering representative to whom a task of this nature is committed is fluently conversant with all of the details of welding design, technique and procedure, such an officer should, by every available means, endeavor to assure himself of the competency, qualification and fidelity of the organization, and of the proper character and condition of the appliances to be used in the work. While such an investigation must, in each individual case, be suited to the peculiar needs of the situation, the following general considerations are suggested as covering the more important phases of the matter:

1—Each member of the operative force should be required to furnish proof of his experience and qualifications, and should be examined periodically, approximately four times each year, to see that he is capable of maintaining proper standards of workmanship. To this latter end he should be required to make test welds, upon the quality of which his assigned status for the ensuing term would be established.

2—If the work is performed under a contract, the contractor should be required to submit evidence of his qualifications and experience, the competency and organization of his forces, the adequacy and suitability of his equipment. The body letting the contract should reserve the right to enforce dismissal of any employee or removal from the work of any equipment which it may deem proper in the interest of securing satisfactory performance.

3—The inspection force should be properly qualified, adequate and of assured fidelity. It should be entirely independent of the operative force.

Tests

A difficulty which, at the present stage of the art, is associated with the use of welded connections arises from the impossibility of accurately determining by visual examination the quality of a weld. However, while the character of the metal composing the interior of a weld is not fully apparent from surface indications, these afford at least a partial clue to the nature and serviceability of the connection, which should, in no case, be neglected.

Laboratory and, to some extent, shop investigations of welds by the use of invisible rays, which penetrate solids and record themselves upon sensitized plates, that is, the X-ray, Gamma-ray, etc., are possible, but such procedure is, at present, expensive, and requires equipment, the use of which would be highly difficult under field conditions in general, and practically impossible in the inaccessible situations of many connections. Such processes are in the course of development and improvement, but are, at this time, neither economically nor physically practicable for general use, especially in the field. Similar comment may be made concerning attempts to determine the interior character of welds by observing the behavior of the electric current when caused to traverse such parts. The magnetic properties of the material also appear to embody the possibility of a clue to the quality of weld metal. This highly-important field of non-destructive tests is now in process of skilled and industrious exploration, and it seems reasonable to anticipate that, in the not distant future, convenient portable appliances for conducting tests by one and possibly all of the media enumerated will be available for use.

At the present stage of the art, it appears that efforts to insure the quality of welds should be directed along the lines of enforcing the highest attainable standards for appliances, material and personnel, close and competent supervision of the work throughout its progress, careful visual examination of completed welds by competent inspectors, and the rejection, removal and replacement of all welds whose quality is, in any degree, a matter of doubt. The field records should comprise an accurate and detailed register, citing the history of each welded connection, including the operator responsible for the workmanship and the engineer or inspector responsible for its final acceptance.

Gas Welding of Class I Pressure Vessels*

By G. W. PLINKE†

WITH the adoption of the A. S. M. E. Code for Unfired Pressure Vessels and Power Boilers in 1931, certain standards were established for the physical properties of weld metal in steel plate construction. Three classifications were determined which were originally designated as Class I, Class II and Class III. In Class I the highest weld qualities and most stringent requirements of construction were specified, including stress-relieving of the entire vessel and X-ray examination. The highest operating fiber stress was permitted for this class of construction and no limitations were placed on pressures, temperatures or service conditions. The welding of power boilers was limited to this class of construction.

In the two other classifications the weld quality and construction requirements were somewhat reduced with a reduction in permitted operating fiber stress, and limitations of the pressure, temperature and service conditions.

Early Experiments

During the early attempts to perfect the applications of welding to pressure vessel construction to meet Class I requirements, oxyacetylene welding was somewhat neglected and its possibilities overlooked. This can probably be accounted for by the fact that most of the

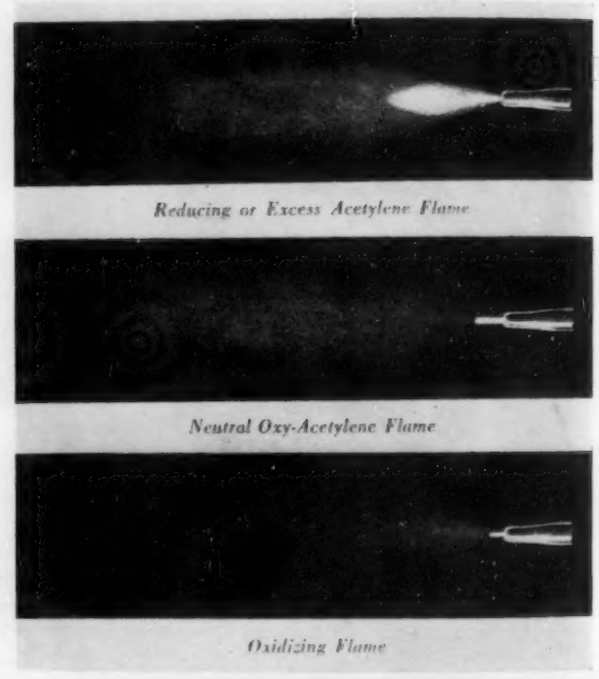


Fig. 1—Three Types of Oxyacetylene Flames: A Slightly Reducing or Excess Acetylene Flame Was Found to Be the Most Satisfactory

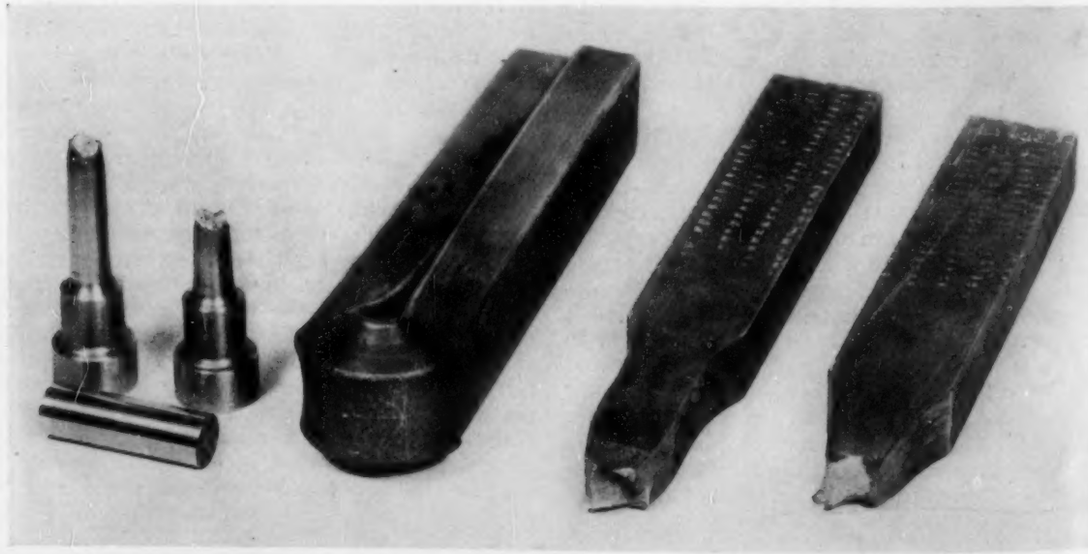


Fig. 2—Test Specimens Complying with A. S. M. E. Class I Requirements. Left—This All-Weld-Metal Specimen Showed 21.5% Elongation. Later Developments Brought This Figure up to 37%. Center—Bend Elongation of 75% Was Attained at the Welded Joint. Right—Tensile Strength Was Quite Satisfactory on Reduced Section Tests

* Read at the 36th Annual Convention, International Acetylene Association, Cleveland, November 12, 13, 14 and 15, 1935.
** Short biographical sketch of the author given at conclusion of this paper.
† Director of Research, Henry Vogt Machine Company.

Physical Test Data (Gas Weld)

Specimen Number	1	2	3	4	5	6
Reduced Section Tensile Test (lb. per sq. in.)	65800	57800	60000	60000	59700	62300
0.505 in. dia. All-Weld Tensile Test (lb. per sq. in.)	66200	60400	60200	63900	63150	66950
Elongation in 2 in. (per cent)	20.5	23.5	25.5	26.0	31.0	34.0
Free Bend Test (elongation in per cent)	42.7	60.4	75.9	56.9	43.8	39.2
Specific Gravity	7.90	7.91	7.90	7.86	7.87	7.91

Specimens stress relieved at 1200° F. for 1 hr.
Average Charpy impact test (ft.-lb.)—25.6
(10 mm. sq. std. key-hole)
(Number of specimens—12)

Fig. 3—Physical Test Data of Oxyacetylene Welded Plate

construction in this class required thicknesses above which the oxyacetylene process appeared to be commercially applicable. Then, too, the electric process indicated greater economy and ease of securing the required physical results with multi-layer deposit. The oxyacetylene process was therefore confined in application to construction equivalent to Class II requirements and no particular attention was paid to developing a procedure to accomplish the physical properties specified in Class I construction.

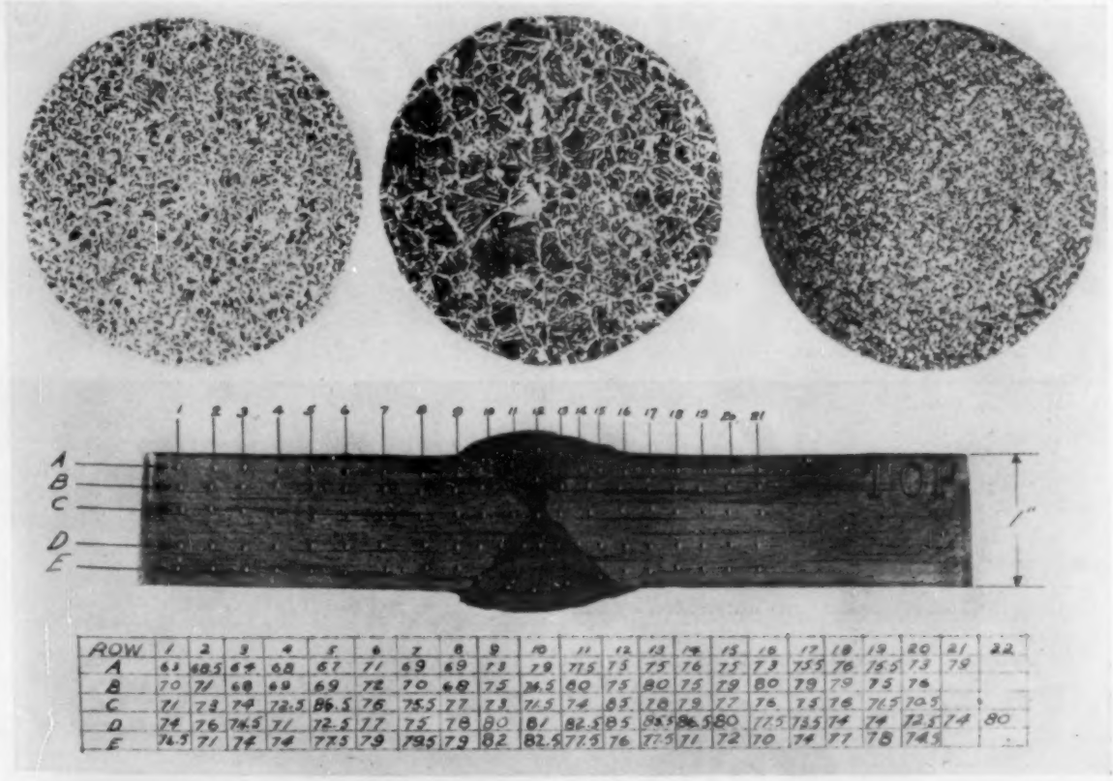
After several years of experience fabricating welded pressure vessels and power boilers in accordance with Class I construction, using the coated electrode electric arc process with the required special technique of control, we began to make some investigations regarding the possibilities of oxyacetylene welding. Numerous tests were made to determine the physical properties of the weld metal using regular gas welding procedure. The early results showed that the tensile strength was generally satisfactory but the ductility, particularly on plate thicknesses above $1/2$ in., was not sufficient to meet Class I Code requirements.

To overcome this difficulty various types of experimental welding grooves were employed. Best results in the heavier plate thicknesses were obtained with the double vee groove, with the U-type groove showing good possibilities in plate thicknesses from 1 in. upward. The U-type groove, however, required a special technique and care had to be exercised to prevent the molten metal from running in front of the puddle and causing laps.

In experimenting with the various types of grooves, it was found that laps and non-fusion along the side walls could be entirely overcome. Laps were frequently found where the operator changed his welding rod and in starting up again failed to get the parent metal to a sufficiently high temperature to fuse properly with the newly deposited metal. Non-fusion was largely due either to welding at too great a speed and neglecting to notice whether the metal was actually fusing into the side walls, or to the operator's depositing too heavy a layer of weld metal in one pass in the groove.

Flame Adjustment and Control Important

Another variable investigated which seemed to give a very definite improvement in welding was the proper adjustment and maintenance of the type of flame employed. Prior to this investigation a so-called neutral flame had always been used. However, it was found that a reducing or slightly excess acetylene flame materially improved the ductility of the weld metal and such defects as porosity or oxide inclusions were practically eliminated. Proper regulation of the flame was then carefully studied and steps were taken to govern the stability of the flame so as to keep it as nearly constant as



ROW	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
A	63	68.5	69	68	67	71	69	69	73	79	77.5	75	75	76	75	73	75.5	76	75.5	73	79	
B	70	71	68	69	69	72	70	68	75	76.5	80	75	80	75	79	80	79	79	75	76		
C	71	73	74	72.5	86.5	76	75.5	77	73	76.5	74	85	78	79	77	76	75	76	76.5	70.5		
D	74	76	76.5	71	72.5	77	75	78	80	81	82.5	85	85.5	86.5	80	77.5	75.5	74	74	72.5	74	80
E	76.5	71	74	74	77.5	79	79.5	79	82	82.5	77.5	76	77.5	71	72	70	74	77	78	74.5		

Fig. 4—Micrographs of Cross Section of Plate, Fusion Zone and Weld Metal Show Freedom from Defects Including Laps and Non-Fusion. Etched 2% Nital. X 50

Fig. 5—Oxyacetylene Welded Specimen Showing Rockwell Hardness of Plate, Fusion Zone and Weld. Specimen Was Stress Relieved at 1200° F. for 1 Hr.

Fig. 6—Exograph Showing Quality of Weld along Line of Fusion

practical. Numerous test plates were welded, stress relieved at 1200° F. and X-rayed. The exographs of these welds showed exceptionally good quality.

The proper type of flame in gas welding causes a protecting gas envelope around the molten metal and prevents the formation of nitrides and oxides in the weld metal due to infiltration of contaminating gases much the same as does the coating on the electrode used in electric arc welding. Figure 1 illustrates types of flames normally used in gas welding. The flame used to produce the high quality welds referred to is a modification of the reducing type flame illustrated.

Tests Reveal Splendid Characteristics

Consideration was also given to the effect of subsequent heat-treatment for grain refinement. Heating above the critical temperature for recrystallization of the weld metal and heat-affected zone naturally gave a considerably finer grain structure. Although the ductility was somewhat improved through this procedure, satisfactory results were obtained without employing it. Oxyacetylene equipment for locally heat-treating the welds was not available and, furthermore, the problem of controlling distortion caused us for the time being to eliminate this operation.

The final physical tests revealed weld metal which was of high quality and generously met all the requirements of the A. S. M. E. Code for Class I welding. An encouraging fact was the consistency of results as shown by repeated tests. Figure 2 is a photograph of actual specimens on completion of test. Figure 3 gives test data which fulfils all Code requirements.

It will be noted that the average value for the Charpy impact test was 25.6 foot-pounds. This test, taken from twelve different specimens, showed results from 22 up to 32 foot-pounds Charpy 10 mm. sq. impact specimens. Although the A. S. M. E. Boiler Code does not require Charpy Impact Tests, this property of the welded joint was investigated because of its significant value.

To demonstrate further the high quality of weld developed by this gas welding procedure the microstructure of the weld metal, the fusion zone and adjacent to the fusion zone were carefully studied. Freedom from defects including laps and non-fusion is illustrated by the photomicrographs shown on Fig. 4.

It is evident that the welding has altered the grain structure somewhat. Some grain growth is apparent adjacent to and along the line of fusion due to the effect of the high temperature which this zone was subjected to for a short time. A study of the physical qualities within this affected zone reveals a slightly higher tensile strength with an insignificant decrease in ductility.

As another check on the comparative quality of the weld metal and the base metal a hardness exploration was made. This covered the unaffected base metal, the heat-affected zone and the weld metal across a typical gas weld after ordinary stress-relieving at 1200° F. The results of this exploration are indicated in Fig. 5. It is interesting to note that there is no important increase in hardness at any point within the weld metal or the heat-affected zone as compared with the unaffected base metal. This further illustrates that in effect there is but one continuous piece of metal across the weld rather than two plates connected by a joint of widely dissimilar hardness characteristics.

With the proper method well established for gas welding to produce physical qualities in the weld metal equal to or better than those required by the A. S. M. E. Code for Class I work, necessary steps were then taken to qualify a number of welding operators. By following the carefully prescribed technique the welders readily qualified and demonstrated their ability to obtain welds having consistent physical properties with good ductility.

Fabrication Work Started

Shortly after qualifying our welders we received an order to fabricate a Class I gas welded vessel, 5 ft. 6 in.

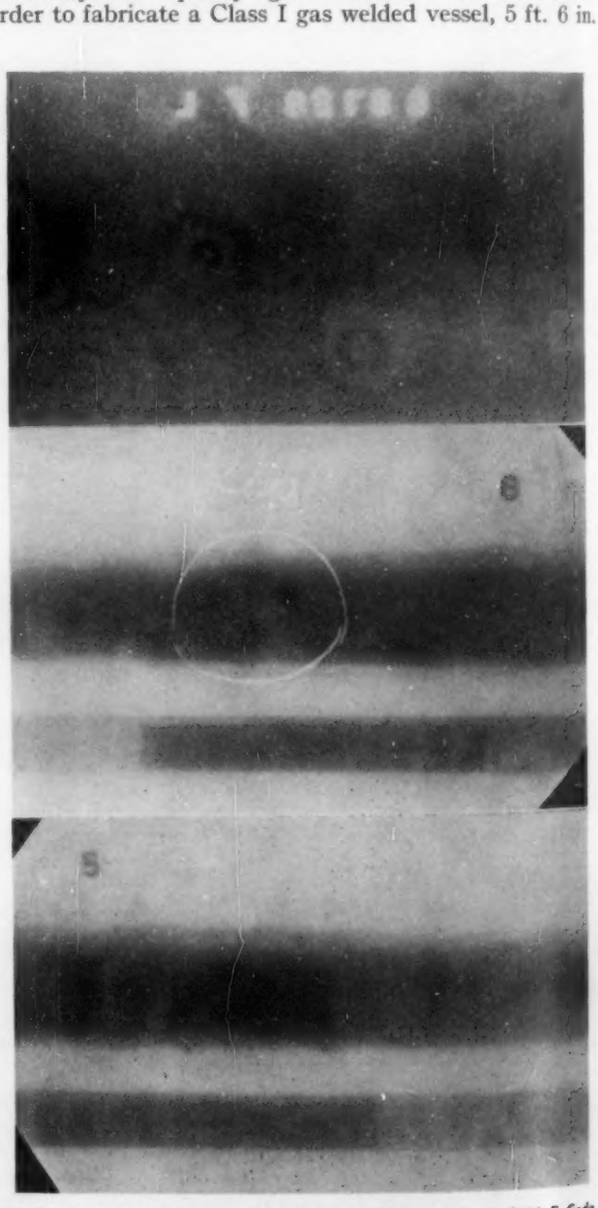


Fig. 7—Comparative Exographs. Top—Permissible Defects under A. S. M. E. Code Regulations. Middle—Type of Defect Found in Vessel at a Few Points. Bottom—Typical Weld without Defects

in diameter and 13 ft. long, having a wall thickness of 1 in. and constructed for a working pressure of 250 lb. per sq. in.

The plates and heads were prepared with a double vee type groove and the shell blocked and rolled preparatory to welding. After rolling, the shell was carefully tack-welded approximately every 12 in. for the full length of the longitudinal seam leaving $^{3}/_{16}$-in. space in the clear between the edges of the vee type groove. The first layer of weld metal was applied from the inside of the shell, every precaution being taken to see that the welders used the same procedure and technique in welding as was used on the qualification plates. Upon completion of the first layer of weld the seam was inspected and cleaned. Then the second layer of weld was applied of sufficient thickness to bring the height of the reinforcing layer $^{1}/_{8}$ in. above the surface of the plate in accordance with Code requirements. After this second layer of weld deposit had been applied on the interior of the drum, the welder had the exterior portion of the groove properly prepared by chipping to receive the first outside layer of weld metal. In chipping out and preparing the groove sufficient metal was removed to insure getting down to good, clean metal of the first layer of weld which had been applied inside.

The balance of the groove was then welded, using the same procedure described for the inside of the shell.

Preliminary Inspection by X-Ray

Upon completion of this welded seam very little distortion was observed but to insure extra good roundness and alignment the shell was re-rolled. It was then taken to the X-ray machine and the longitudinal seam X-rayed. At this point it was suggested by the insurance inspector that, in addition to the regular X-ray procedure, several exposures be made along the line of fusion at an angle of approximately 45 deg. to the tangent line at the weld to ascertain whether the exograph would show any slight indication of non-fusion. The suggestion was carried out and there was positively not even an indication of lack of fusion. The exograph in Fig. 6 illustrates the quality of weld along this line of fusion.

The exographs of the longitudinal seam were inspected and three small defects were questioned. These questionable flaws were located on the seam and the weld metal chipped out. At two of these points small defects were found, one consisting of a concentrated area of porosity near the outside surface of the outer layer of weld and the other a small area of non-fusion in the center of the seam. The latter defect was undoubtedly due to failure of the operator to chip out sufficient metal from the first applied layer of weld in preparing the groove from the outside preparatory to welding. No defect was found at the third questionable point, although the weld metal was chipped out entirely through the weld. These places were then repaired, the welds X-rayed and the exographs inspected and approved.

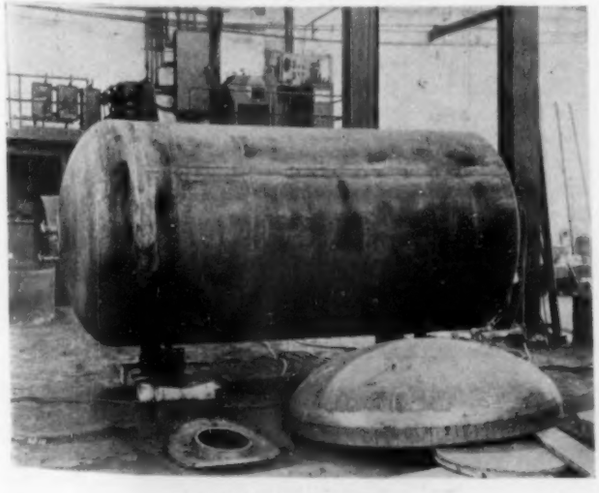


Fig. 8—Vessel under Construction

Fig. 9—Operator Welding the Outside Girth Seam

The heads of the vessel were then fitted to the shell, tack-welded in place and the seams welded, using the same general procedure as in welding the longitudinal seam. We expected some distortion of the shell during the welding of the girth seams but due either to the method of procedure or to the thickness and rigidity of the plate there was little or no distortion. Both seams were then X-rayed and the exographs inspected. Very few defects were found and those found were only of a minor nature. These were chipped out, repaired and again X-rayed. In Fig. 7 an interesting comparison is shown in the three exographs. The top exograph is typical of the permissible defects under A. S. M. E. Code requirements. This exograph was obtained from the A. S. M. E. Boiler Code Committee. The middle exograph shows the extent of the defects found in the vessel at a few points. The third or bottom exograph shows a typical weld without defects.

The manhead and the nozzles were then fitted and welded to the vessel. The vessel was then stress-relieved at 1200° F. in accordance with the A. S. M. E. Code requirements. Upon completion of the stress-relieving treatment, the vessel was given the prescribed hydrostatic test. Figures 8 and 9 show the vessel under construction.

Rigid Control Maintained

Since this was the first gas welded vessel constructed to meet Class I requirements of the A. S. M. E. Unfired Pressure Vessel Code, a most rigid system of inspection

and control of all the details of construction, as well as the inspection of the exographs of the welded seams, was maintained at all times. Commercial standards of quality for Class I construction per A. S. M. E. Code would not have required the removal and rewelding of any of the spots located. The repairs which were made were only of very minor extent and were made only to satisfy our own rigid requirements.

The idea has been quite prevalent among fabricators of pressure vessels that gas welding causes considerable distortion. However, this vessel showed practically no distortion. If proper care is exerted in fitting up, and if the shell is re-rolled before applying the heads, there should not be a great amount of distortion particularly when the shell thickness is $^3/_4$ in. and heavier.

Costs Can Be Lowered

The cost of fabricating this vessel was considerably in excess of the cost of an equivalent vessel fabricated by electric welding. The first cost of any new process is unavoidably high due to lack of facilities and experience. A personnel for this type of work had to be established, welding operators trained and qualified and a thorough procedure control developed. As more gas welded vessels are fabricated to meet Class I requirements, the cost will naturally be reduced.

For example, single flame hand torches were used throughout in the welding of this vessel. This was necessary as no technique or procedure had been established and worked out for application to heavy plate of the multi-flame torches or semi-automatic equipment with gravity fed welding rods, such as is being employed on pipe and light plate. The development of such equipment for application to heavy plate welding will undoubtedly materially reduce the cost of oxyacetylene welding. With this equipment the heat required for preparing the base metal and welding rod and for maintaining the required welding puddle can be produced and controlled by individual tips, each performing its required function. The separate control of the heat and the deposition of the welding rod in gas welding appears to offer a definite advantage over electric welding where this flexibility of control is not present. This should be particularly important in future developments leading toward the more rapid deposition of weld metal. Full mechanization of the application of the oxyacetylene process also seems to have some very definite possibilities.

There are two other factors which seem to favor further developments of oxyacetylene welding for Class I construction, now that it has been well demonstrated that the physical requirements may be readily complied with.

In the gas welding of Class I pressure vessels the exographs will and should reveal welds that are practically flawless and chipping out of defects and repairing of welds should be largely eliminated. Repairing of welded seams during the course of construction is a costly procedure and its elimination would materially reduce the cost of welded fabrication.

Because of the lower temperature gradient established between the base metal and weld metal in gas welding, residual stresses are not as highly concentrated as in electric welding. Although Class I vessels are stress-relieved to relieve such stress concentration, this factor may at times require special procedure for electric weld construction which would not be required were gas welding employed.

As this was our first Class I gas welded vessel to be X-rayed and tested in accordance with the A. S. M. E. Code, no definite speeds had been developed in our technique so as to place the drum on power rollers in order to revolve it during welding. Therefore, we placed it on ordinary rollers and rolled it by hand to take care of positioning it for the welding operator while he welded the girth seams.

We have since conducted some experimental work on speeds for gas welding with the work placed on mechanically operated rollers and predict that important time savings will be made in welding girth seams of vessels.

Benefits of Envelope Flame

Since it has been learned that practically the same protecting atmosphere surrounding the molten puddle of weld metal can be obtained with the proper gas flame as is now obtained with the correct coating on an electrode in electric arc welding, a new field of development for improving gas welding technique appears feasible. For some time it has been the aim and hope of manufacturers of welded products as well as electrode producers to develop a satisfactory automatic electric welding machine using covered electrodes which would consistently produce Class I welding resulting in a saving in time and cost of materials. Some very practical machines have been developed, but none are acceptable from the standpoint of economy and consistency of results as required in commercial production.

With the knowledge gained from the investigation of atmospheres developed by gas flames, it seems that in the near future an automatic welding machine will be developed which will combine and make use of the good qualities found in both the gas and electric processes. With a combination of these two processes, it is entirely feasible that an automatic machine can be built to use a coil of bare wire electrode which will make the welding operation continuous while the necessary atmosphere, so essential to good quality welding will be secured through the application of gases from some combination of oxygen and acetylene or other available gases. When such a machine is perfected welding costs will be greatly reduced and an important forward step made in the art of uniting metals for industrial purposes.

* * * * *

G. W. Plinke

G. W. Plinke is Director of Research, Henry Vogt Machine Company, Louisville, Kentucky.

Mr. Plinke is a graduate of Purdue University and holds the degree of Bachelor of Science in Mechanical Engineering. He joined the Henry Vogt Machine Company in 1924 and in 1930 was put in charge of development work and welding.

In his capacity as director of research and of development work in welding, Mr. Plinke has devoted a major portion of his time to the study of welding carbon and alloy steels. He also has done considerable work on the X-ray testing of welds and is the author of a number of publications on welding and X-ray testing technique.

Fundamentals of Spot Welding with Particular Reference to Electrode Life*

By E. I. LARSEN

Introduction

A GREAT many papers have been published on the general subject of resistance welding. These papers have dealt with a wide variety of problems. Only brief mention has been made, however, of what is a very important part of the subject—namely, the life of the electrode used in making a resistance weld. It is this part of resistance welding with which the present paper is concerned. Papers by Zimmerman,[1] Briggs,[2] Ruppen[3] and Komovski[4] have dealt with this subject but not in great detail.

In the past pure copper was used almost exclusively as an electrode material. Recently several new electrode materials have come into prominence. The work described here was undertaken to establish what relationship exists between copper and some of the new alloy welding electrodes.

In studying the life of electrode materials particular attention was given the following factors:

(*a*) *Electrical and Heat Conductivity*

It is essential that the electrical conductivity of a spot welding electrode be sufficiently high so that under correct operating conditions of pressure, etc., heating will occur at the joint of the materials to be welded and not between the electrode face and the stock to be welded; otherwise sticking of the electrode may occur. It is important that the heat conductivity be good so that the electrode can dissipate the heat generated during the welding operation.

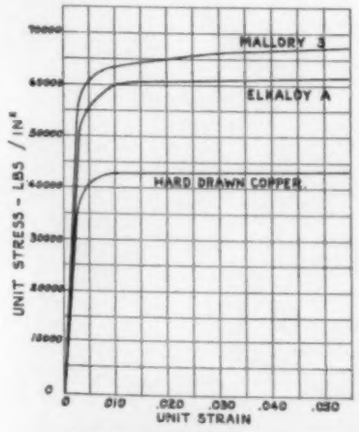
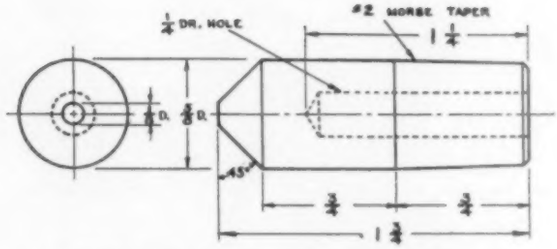


Fig. 1

STRESS - STRAIN CURVES OF MATERIALS USED IN TESTS.



TYPE OF TIP USED IN TESTS

Fig. 2

(*b*) *Tensile Properties*

The yield point of electrode materials is important in resistance welding because the electrode material will flow plastically during the welding operation. The ability of the material to retain a reasonably high yield point at slightly elevated temperatures is important because of the rise in temperature to which the electrode face is subjected.

Nearly all hardness measurements depend upon a plastic flow of the material during testing. The hardness value, therefore, has a definite relationship to the tensile properties and can be taken as an indication of the ability of the electrode material to withstand plastic deformation.

(*c*) *Electrode Design*

The design of a spot welding electrode will have a great deal to do with the life of the electrode during operation. As has been pointed out by other investigators there is almost an unlimited number of designs of electrodes possible. In many cases the design will be dictated by the type of work to be welded. Very often, however, it is possible to make improvements by allowing for better heat distribution and heat dissipation in the solid metal parts of the tip.

(*d*) *Cooling*

Practice has shown the enormous importance of water cooling of spot welding electrodes. By this means alone the life of spot welding electrodes can be increased considerably because the temperature of the metal is kept below the annealing or recrystallization point. Some electrodes have been designed so that the water cooling has been brought to within a small fraction of an inch of the welding face; in other tips the cooling has been kept quite a distance away from the welding face. In some designs the water hole has been made so large that only a shell of the electrode remains. As is usual in most engineering problems a compromise is necessary.

(*e*) *Welding Pressure*

Another important factor in resistance welding and particularly with reference to the life of spot welding

* Paper presented January 17, 1936, at the S. A. E. Annual Meeting.

[1] Zimmerman, "Spot Welding Problems," AMERICAN WELDING SOCIETY JOURNAL, Dec. 1935, p. 20.

[2] Briggs, "Size and Spacing of Spot Welds," AMERICAN WELDING SOCIETY JOURNAL, Nov. 1934, p. 25.

[3] Ruppen, "Wear Resistant Elkonite and Elkaloy Electrodes for Resistance Welding and Heating," *Electrowärme*, vol. 4, June 1934, p. 138.

[4] Komovski, "A New Design of Spot Welding Electrode," AMERICAN WELDING SOCIETY JOURNAL, July 1935, p. 14.

electrodes is the welding pressure. These pressures may vary from 10,000 lb. per sq. in. to values as high as 50,000 to 60,000 lb. per sq. in. according to the type of material welded. If the welding pressure is maintained at a value higher than the yield point of the electrode material then the electrode will flow plastically or "mushroom." If this would occur at room temperature then the cold work would harden the metal. In most cases, however, the temperature is near the softening point and no beneficial but rather detrimental effects result.

Electrode Materials Tested

In conducting the present tests, three types of materials were used—namely, pure copper, Elkaloy A and Mallory 3. Figure 1 shows the stress-strain curves of these materials:

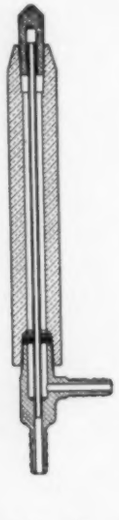


Fig. 3—Sectional Drawing of Tip

In Table 1 are listed the physical properties:

Table 1

Material	Elastic Limit, Lb. per Sq. In.	Ult. Strength, Lb. per Sq. In.	Rockwell B Hardness	% Conduct. Cu = 100%	Annealing Temp., ° F.
Copper	7,000	35,000	50	98	370
Elkaloy	45,000	65,000	70	80	660
Mallory 3	50,000	70,000	80	80	1000

Test Set-Up

The type of electrode used in the present tests is shown in Fig. 2.

In some preliminary tests it was found that the weight change and length change were negligible, the principal deterioration of the electrode being in the increase in area of "mushrooming" of the welding face. The tip used in these tests was so designed that "mushrooming" would occur relatively slowly and yet could be measured with a fair degree of accuracy. The diameter of the welding face was made approximately three times the thickness of the material to be welded. In all of these tests the thickness of the material welded was 0.040 inch.

In Fig. 3 is shown a sectional drawing of the tip, holder and water cooling assembly.

The welder on which these tests were run is a 20-kw. manually operated machine. The timer was of the mechanical type and was adjusted to maintain the welding current for a period of approximately one-quarter second. Pressure on the electrodes was exerted through a calibrated spring. A stop was built on the welder so that the pressure on the electrodes could be adjusted to the desired value and maintained. A pressure of 15,000 psi on the electrodes was selected as being good welding practice on the materials welded. Welds were made at the rate of approximately 50 per minute.

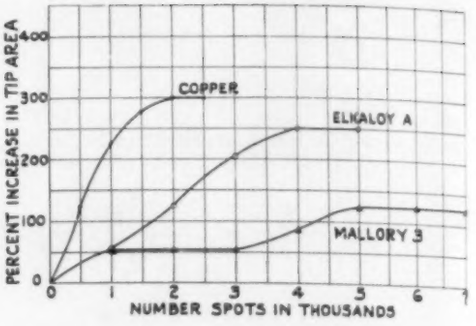


Fig. 4

INCREASE OF TIP AREA DURING WELDING.
MATERIAL WELDED – COLD ROLLED STEEL
MATERIAL THICKNESS – .040"
INITIAL TIP PRESSURE – 15000 PSI
INITIAL TIP DIAMETER – .125"

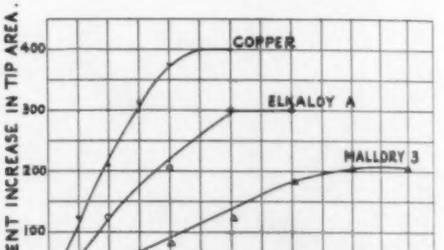


Fig. 5

INCREASE OF TIP AREA DURING WELDING
MATERIAL WELDED – TERNE PLATE
MATERIAL THICKNESS – .040"
INITIAL TIP PRESSURE – 15000 PSI
INITIAL TIP DIAMETER – .125"

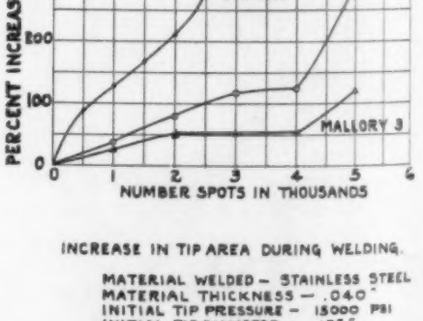


Fig. 6

INCREASE IN TIP AREA DURING WELDING.
MATERIAL WELDED – STAINLESS STEEL
MATERIAL THICKNESS – .040"
INITIAL TIP PRESSURE – 15000 PSI
INITIAL TIP DIAMETER – .125"

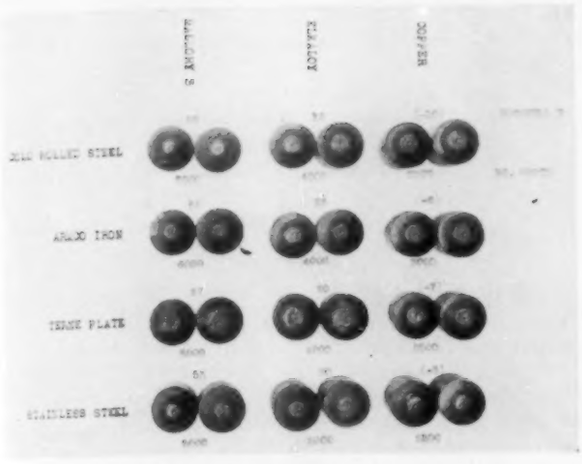


Fig. 7—Tips after Testing

Test Results

Two types of tests were run. In the first test the initial tip pressure was 15,000 lb. per sq. in. Welds were made on various types of materials, and the increase in tip area determined at various intervals. Welds were tested periodically by bonding the two sheets back and forth in opposite directions until fracture occurred. A weld was considered good when a slug could be pulled from the sheet. As the electrodes increased in area it was necessary to increase the "heat" to insure good welds. In general the "heat" was raised after the tip had increased in area 200%.

Curves were plotted showing the increase in tip area during welding versus the number of spots. Figures 4, 5 and 6 show the increase in tip area during welding of cold-rolled steel, terne plate and stainless steel.

The electrodes tested were copper, Elkaloy A and Mallory 3. Figure 7 is a photograph showing the condition of the tips after testing. The small round dot in the center of the welding face of each electrode is a Rockwell hardness impression.

In testing the materials by this method the tip pressure in pounds per square inch decreases as the electrode "mushrooms" according to the curve shown in Fig. 8.

The decrease in tip pressures resulting from an increase in tip area during the welding of terne plate with the three types of electrode materials is shown in Fig. 9.

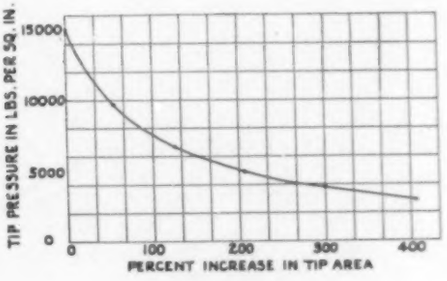
In the second type of test the electrode pressure was held constant at 15,000 lb. per sq. in. That is, as the electrode point area increased during welding the electrode pressure was increased so as to keep the pressure per unit area constant. Figures 10, 11 and 12 show the results of this type of test. As could be expected the increase in tip area is much faster.

As an example copper electrodes increased 400% in tip area in 1000 spots when welding cold-rolled steel at a *constant* pressure of 15,000 psi as compared to 300% in 2000 spots when the tip pressure decreased during welding.

In the first test the electrode "mushrooms" until the tip area reaches such dimensions that the total stress in pounds per sq in. is below the yield point of the material at the temperature of operation and plastic yielding does not continue.

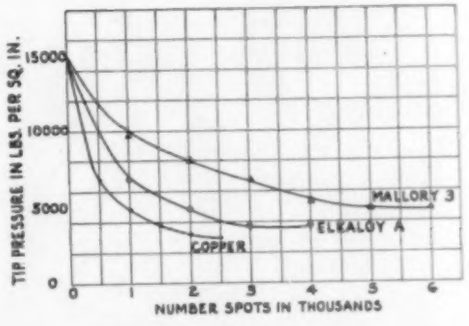
The type of tests described above were relatively simple and test data could be obtained quite rapidly. However, it was thought that there were certain factors in this type of test which might not be indicative of the total life of an electrode. It was therefore decided to run life tests on the three materials. Electrodes of the same design were tested on cold-rolled steel and a sufficient number of spots made to "mushroom" the tip to 225% of its original area. The tip was then redressed to its original shape. A careful record was kept of the weight of material machined away in redressing and of the change in length. The tips were "mushroomed" to 225% and redressed ten times. The number of spots, the amount of material machined away and the change in length per dressing were very constant. Table 2 shows the average number of spots per dressing and the average thickness of material machined away in redressing:

Fig. 8



DECREASE IN TIP PRESSURE RESULTING FROM INCREASE IN TIP AREA DURING SERVICE.

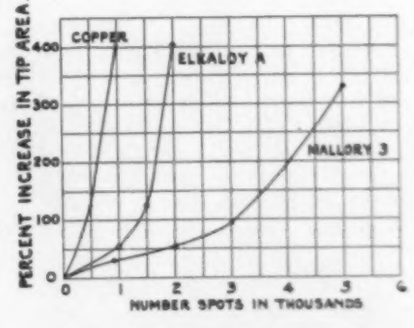
Fig. 9



DECREASE IN TIP PRESSURE RESULTING FROM INCREASE IN TIP AREA ("MUSHROOMING") DURING SERVICE

MATERIAL WELDED - TERNE PLATE
MATERIAL THICKNESS - .040"
INITIAL TIP DIAMETER - .125"

Fig. 10



INCREASE IN TIP AREA DURING WELDING; PRESSURE PER UNIT AREA HELD CONSTANT

MATERIAL WELDED — COLD ROLLED STEEL
MATERIAL THICKNESS — .040"
INITIAL TIP DIAMETER — .125
TIP PRESSURE CONSTANT - 15000 PSI

Table 2

Averages per Dressing	Copper	Elkaloy A	Mallory 3
No. spots	489	1362	4590
Thickness of material machined away in dressing	0.041 In.	0.036 In.	0.024 In.
Spots per inch of electrode	11,927	37,833	191,250

From approximately $^1/_4$ inch for the Mallory 3 to $^4/_{10}$ inch for copper were machined from the welding end of the electrodes in making these tests. It should be remembered, however, that the value given in the number of spots per inch of electrode apply only to these tests and should not be taken as an exact ratio of the superiority of one material over the other. Our experience has shown that in actual production on numerous types of welding problems and equipment the average life ratio of these materials, when used as electrodes, is about as follows: If copper is taken as 1, Elkaloy will be 2 to 3 and Mallory 3, 5 to 7.

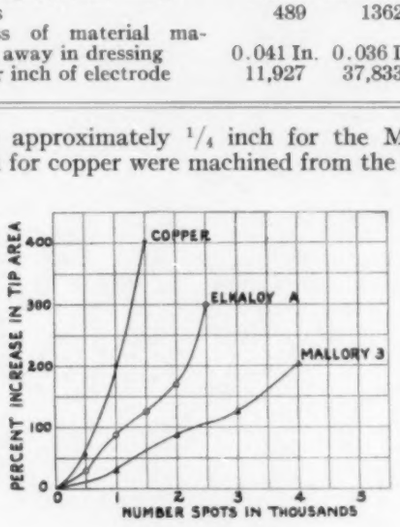


Fig. 11

INCREASE IN TIP AREA DURING WELDING, PRESSURE PER UNIT AREA HELD CONSTANT

MATERIAL WELDED - TERNE PLATE
MATERIAL THICKNESS - .040"
INITIAL TIP DIAMETER - .125"
TIP PRESSURE CONSTANT - 15000 PSI

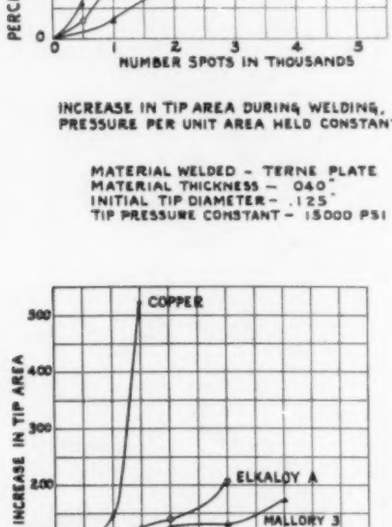


Fig. 12

INCREASE IN TIP AREA DURING WELDING, PRESSURE PER UNIT AREA HELD CONSTANT

MATERIAL WELDED - STAINLESS STEEL
MATERIAL THICKNESS - .050"
INITIAL TIP DIAMETER - .125"
TIP PRESSURE CONSTANT - 15000 PSI

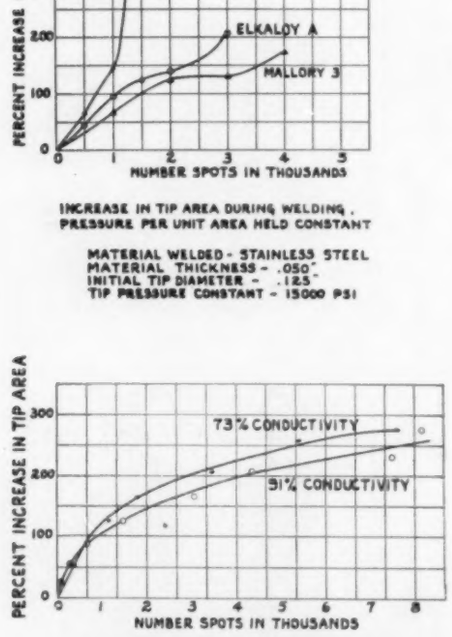


Fig. 13

THE EFFECT OF VARIATION IN THE ELECTRICAL CONDUCTIVITY OF TWO SAMPLES OF COPPER OF THE SAME HARDNESS ON THE INCREASE IN TIP AREA DURING WELDING

MATERIAL WELDED - COLD ROLLED STEEL
MATERIAL THICKNESS - .040"
INITIAL TIP DIAMETER - .125"
INITIAL TIP PRESSURE - 15000 PSI

The interesting point brought out by the life tests is the fact that the results verify the short-time test results shown in Fig. 4. That is to say, the average number of spots necessary to "mushroom" any one of the materials tested to a per cent increase in tip area of 125 (225% original area), is almost identically the same as was found in the short-time test. This indicates that an approximate value of the total life of a spot welding electrode can be calculated by simply determining the number of spots necessary to "mushroom" the electrode to a specified area and measuring the amount of material lost in redressing.

In order to determine the effect of electrical conductivity on the deterioration of spot welding electrodes two special copper alloys were tested. The tensile properties of the two materials were the same. The electrical conductivity of one was 73% and the other 91%.

Tests were run on these two materials to determine the per cent increase in tip area during welding. Figure 13 shows the results of tests on cold-rolled steel in which the initial tip pressure was 15,000 lb. per sq. in.

As can be seen the variation in electrical conductivity of these particular alloys did not have a very great effect on the "mushrooming" of the electrode. In Fig. 14 are curves showing the effect of variation in electrical conductivity when a constant tip pressure of 15,000 lb. per sq. in. was maintained.

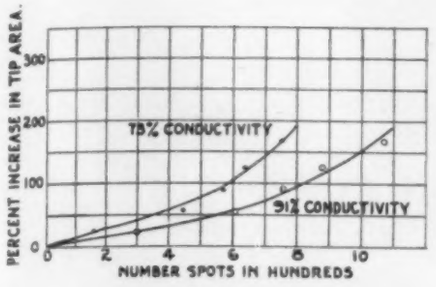
This type of test indicates that the lower conductivity material will have a somewhat shorter life than the material with a higher conductivity. The electrical conductivities of the two alloys were sufficiently high to insure good welding characteristics on steel or ferrous alloys. If the conductivity had been as low as 50%, for example, difficulty in "sticking" of the electrodes to the cold-rolled steel would certainly have been encountered. However, an electrode material having 50% electrical conductivity would perform very well on stainless steel. This is due to the much lower electrical conductivity of stainless steel as compared to cold-rolled steel.

The effect of variation in hardness on the deterioration of spot welding electrodes having the same electrical conductivity was also studied. The two alloys had a hardness of 5 and 75 Rockwell B, respectively. Figures 15 and 16 show the results of these tests.

As was expected and can be seen from the curves, the sample having the low hardness "mushroomed" much more rapidly.

Figures 17 and 18 show the softening of Mallory 3, Elkaloy A and copper electrodes during welding of cold-rolled steel, using a tip pressure of 15,000 lb. per sq. in.

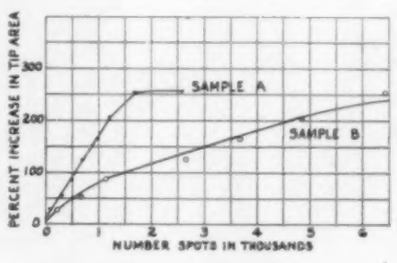
The hardness readings were taken on the welding face of the electrode after a certain number of spots had been welded. A separate electrode was taken for each hardness reading. It is very interesting to note the extreme drop in hardness of copper after only a very few spots. For example, the hardness dropped from 55 Rockwell B in the "cold worked" condition to 23 Rockwell B after only 10 spots; whereas, in Mallory 3 the Rockwell B hardness dropped from 80 to 72, a decrease of only 8 Rockwell B numbersin 100 spots. After 6000 spots the



THE EFFECT OF VARIATION IN ELECTRICAL CONDUCTIVITY OF TWO SAMPLES OF COPPER OF THE SAME HARDNESS ON THE INCREASE IN TIP AREA DURING WELDING.

MATERIAL WELDED - COLD ROLLED STEEL
MATERIAL THICKNESS - .040"
INITIAL TIP DIAMETER - .125"
TIP PRESSURE CONSTANT - 15000 PSI

Fig. 14

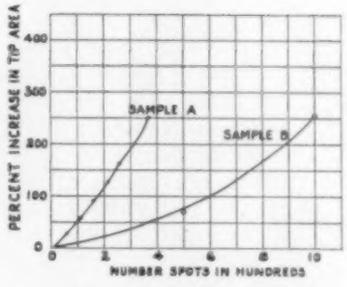


THE EFFECT OF VARIATION IN HARDNESS OF TWO SAMPLES OF THE SAME MATERIAL ON THE INCREASE IN TIP DIAMETER DURING WELDING

MATERIAL WELDED - COLD ROLLED STEEL
MATERIAL THICKNESS - .040"
INITIAL TIP DIAMETER - .125"
INITIAL TIP PRESSURE - 15000 PSI

SAMPLE 'A' - 5 ROCKWELL B
SAMPLE 'B' - 75 ROCKWELL B

Fig. 15



THE EFFECT OF VARIATION IN HARDNESS OF TWO SAMPLES OF THE SAME MATERIAL ON THE INCREASE IN TIP DIAMETER DURING WELDING.

MATERIAL WELDED - COLD ROLLED STEEL
MATERIAL THICKNESS - .040"
INITIAL TIP DIA. - .125"
TIP PRESSURE CONSTANT - 15000 PSI

SAMPLE "A" - 5 ROCKWELL B
SAMPLE "B" - 75 ROCKWELL B

Fig. 16

copper electrode was dead soft whereas Mallory 3 still retained a hardness of approximately 60 Rockwell B.

A comparison of the annealing points of the three materials tested seems to offer an explanation of most of these phenomena. Figure 19 shows the temperatures at which the three test materials will soften.

As can be seen the softening of the welding face of an electrode is a direct function of the annealing temperature of the material. Both Elkaloy A and Mallory 3 have a higher hardness than copper, in the fabricated state, and have the ability to retain this hardness at relatively high temperatures. Cold worked copper will soften at a temperature as low as 370° F.; Elkaloy A will not anneal below 660° F.; and Mallory 3 will retain its hardness when heated to temperatures as high as 1000° F. Samples of Mallory 3 have been heated for hundreds of hours at 750° F. without decreasing the hardness.

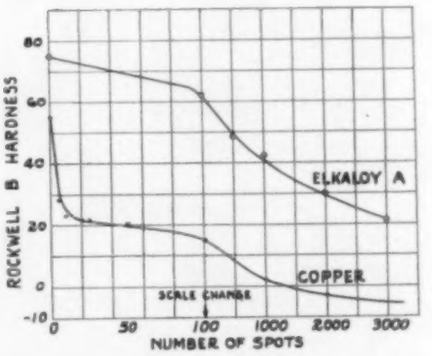
Microstructure of Welds

A microscopic study was made of test-pieces welded under various conditions. Figures 20, 21 and 22 show the microstructure at a magnification of 40 times of samples of cold-rolled steel welded under the following conditions:

(*a*) Figure 20: Low heat, pressure 15,000 lb. per sq. in.
(*b*) Figure 21: Proper heat, pressure 15,000 lb. per sq. in.
(*c*) Figure 22: Excessive heat, pressure 15,000 lb. per sq. in.

Each sample showed the typical elliptical area of large columnar crystals common to a spot weld. The size of the spot, size of the grains adjacent to the spot and the tensile properties of the weld were greatly influenced by the variation in "applied heat."

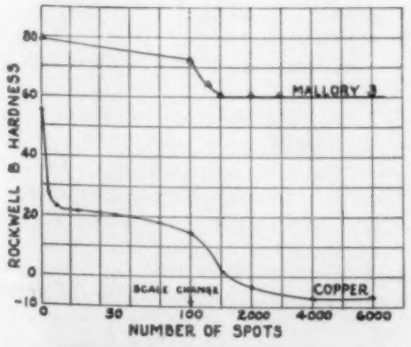
The strength of the weld made with "low heat" indicated the welded area was not large enough with respect to the thickness of sheet. The spot produced by weld-



SOFTENING OF ELKALOY A AND COPPER DURING WELDING HARDNESS READINGS TAKEN ON WELDING FACE

MATERIAL WELDED - COLD ROLLED STEEL
TIP PRESSURE - 15000 PSI

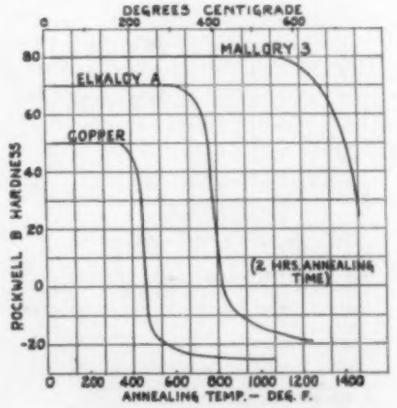
Fig. 18



SOFTENING OF MALLORY 3 AND COPPER DURING WELDING HARDNESS READINGS TAKEN ON WELDING FACE

MATERIAL WELDED - COLD ROLLED STEEL
TIP PRESSURE - 15000 PSI

Fig. 17



THE EFFECT OF ANNEALING AT VARIOUS TEMPERATURES ON THE HARDNESS OF MALLORY 3, ELKALOY A AND COPPER.

Fig. 19

Fig. 20—Low Heat

Fig. 21—Proper Heat

Fig. 22—Excessive Heat

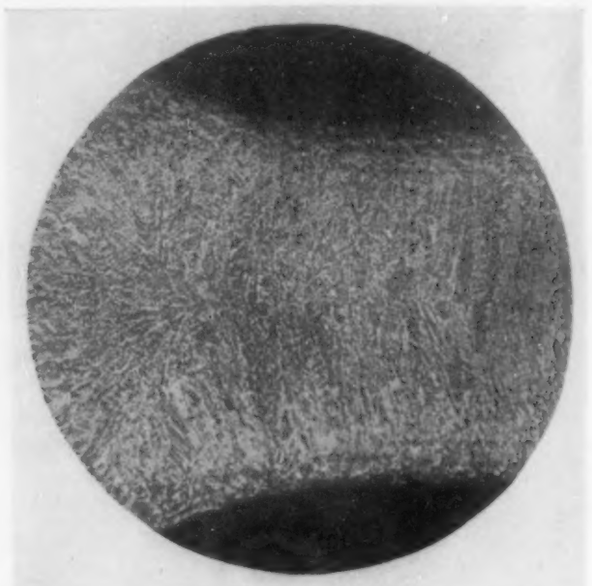
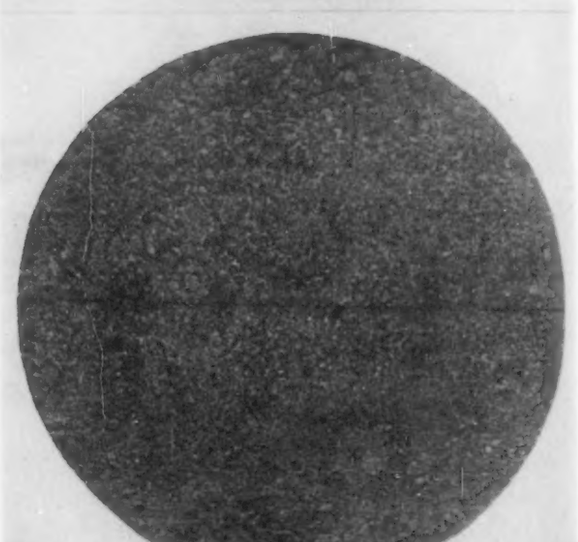


Fig. 23—Low Pressure Due to Mushrooming of Electrodes



ing with the "proper heat" was of good size as compared to the thickness of the sheets. A region of equi-axed grains surrounded the spot.

The structure of the weld shown in Fig. 22 made with "excessive heat" indicates the material was over-heated.

The thickness of the sheets has been reduced to such an extent by the "Brinelling effect" of the electrodes that the strength of the weld will be below normal. Note too, the large columnar crystals extending across the entire thickness of the welded zone.

Figure 23 shows the structure of the weld obtained when the electrodes had increased 300% in area due to "mushrooming" in service and the heat was not raised to compensate for the resulting decrease in pressure.

As can be seen the sheets have not welded in a tight form but merely stuck at several points. Some recrystallization has taken place along the inter-faces of the joint. However, the pressure and the temperature obtained during welding were not sufficiently high to cause many grains to grow across the joint and form a strong weld. There are, however, several areas where recrystallization has taken place and grains have grown across the boundary separating the two sheets.[5]

Figure 24 shows the result of an attempt to rectify the conditions shown in Fig. 23.

The current was raised to what would be ordinarily excessively high. A fair weld was obtained by this practice, but as can be seen from the photomicrograph, the material has not been satisfactorily welded. There is a plane of weakness through the center of the weld along which several voids could be seen.

[5] Hobrock ("Some Fundamentals of Spot Welding," *Metals and Alloys*, Jan., Feb., March 1935) has suggested that the welding process has its basis in the recrystallization of the metal. According to his explanation the pressure required in the process serves several purposes:

1. It presses the surfaces of the two metals together;
2. It breaks through the films of oxide, nitrides and adsorbed gases that are found on the surface; and
3. It provides a small deformation in the crystals of the original material that will permit them to recrystallize. During this process of recrystallization the grains may then grow across the boundary (inter-face) that separated the two pieces. If this grain growth occurs, the two pieces are welded together.

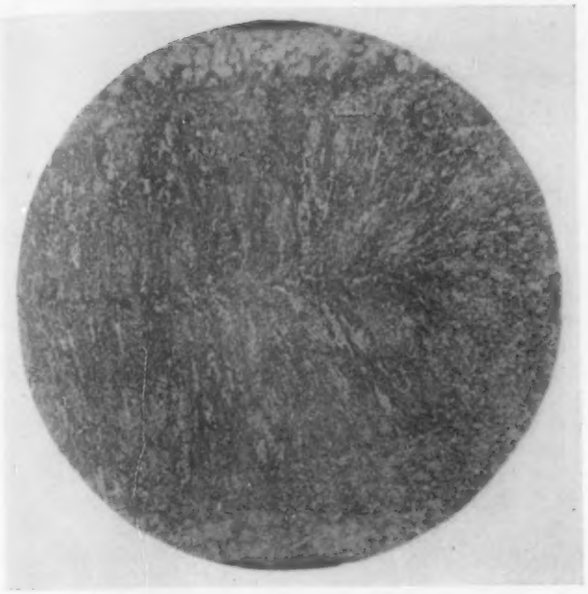


Fig. 24

Conclusions

In the present paper, tests have been reported which were confined to a definite set of conditions and in which as many variables as possible were eliminated.

These tests clearly indicate that the fundamental requirements of spot welding electrode materials are: High hardness, high yield point and high annealing temperature combined with high electrical and heat conductivity.

The outstanding fact brought out by these tests is the importance of the ability of a spot welding material to retain its hardness at elevated temperatures.

Requirements for Repairs by Fusion Welding on Boilers and Pressure Vessels*

1. By "fusion welding" is meant a process of welding metals in a molten or molten and vaporous state without the application of mechanical pressure or blows. Such welding may be accomplished by the oxyacetylene or oxy-hydrogen flame or by the electric arc. Thermit welding is also classed as fusion welding.

2. A major repair by fusion welding, such as the repair or making of a new seam, the insertion of nozzles or any repair involving the safety of a boiler or pressure vessel should be made in accordance with the section of A. S. M. E. Code governing the particular kind of vessel or kind of work to be done. The individual welders employed on such work must have passed satisfactory qualification tests as required by the A. S. M. E. Boiler or Unfired Pressure Vessel Code, and particular attention must be given the requirement that the position (flat, vertical or overhead) in which the welding is done on the test-piece shall be the same as will be encountered in making the repair.

NOTE: The 1934 revision of the Unfired Pressure Vessel Code changes the designation and stamping of fusion welded vessels as follows:

"Class 1 vessels" to "vessel built in accordance with paragraph U-68"
"Class 2 vessels" to "vessel built in accordance with paragraph U-69"
"Class 3 vessels" to "vessel built in accordance with paragraph U-70."

* National Board of Boiler Pressure Vessel Inspectors, Columbus, Ohio (approved October 24, 1935).

3. *No Welding Repairs Shall Be Made Before an Inspection Has Been Made by an Authorized Inspector and the Method of Repair Sanctioned by Him.*—If, in the opinion of the inspector, a hydrostatic test is necessary such test shall be applied when the work is completed.

4. Fusion welding on boilers or pressure vessels by unqualified welding operators will not be acceptable except in the cases specified herein where the safety of the boiler or pressure vessel does not depend upon the weld.

(*a*) Fusion welds not exceeding three feet in length will be permitted in a stay-bolted surface or one adequately stayed by other means so that, should the weld fail, the parts would be held together by the stays.

(*b*) Cracks in girth seams extending from the edge of the plate to the rivet hole may be fusion welded. All cracks that may be welded shall be properly prepared to permit fusion through the entire thickness of the plate. Similar cracks in a longitudinal direction and located between the rivet holes may also be fusion welded, provided the cracks do not extend more than 3 in. beyond the edge of the lap of the inner plate. Cracks extending from rivet hole to rivet hole on girth seams shall not be welded.

(*c*) Calking edges of girth seams may be built up by fusion welding under the following conditions: The thickness of the original metal between rivet holes and calking edge to be built up shall be not less than $^1/_4$ of the diameter of the rivet hole and the portion of the calking edge to be replaced shall not exceed 30 in. in length in a girthwise direction.

(*d*) Prior to making any repairs to girth seams by fusion welding the rivets shall be removed over the portions to be welded and for a distance of at least 6 in. beyond each such portion. After repairs are made the rivet holes shall be reamed before the rivets are redriven.

(*e*) When external corrosion has reduced the thickness of plate around handholes to an extent of not more than 40% of the original thickness and for a distance

not exceeding 2 in. from the edge of the hole, the plate may be built up by fusion welding.

(*f*) Stayed sheets which have corroded to a depth of not more than 40% of their original thickness may be reinforced or built up by fusion welding. In such cases the stays and stay-bolts shall come completely through the reinforcing metal and the original ends of the stay-bolts shall be plainly visible to the Inspector. When necessary to replace stays and stay-bolts, they shall comply with the requirements of the A. S. M. E. Code.

(*g*) In fire tube boilers where tubes enter flat surfaces and the tube sheets have been corroded or where cracks exist in the ligaments, fusion welding may be used to reinforce or repair such defects. The ends of such tubes may be fusion welded to the tube sheets after they have been rolled and beaded. Such repairs for tube sheets and the welding in of tubes in the sheets shall not be permitted where such sheets form the shell or drum of a water tube boiler.

(*h*) Unreinforced openings in the shells or drums of boilers or pressure vessels, provided they do not exceed in diameter the sizes of unreinforced openings permitted by the A. S. M. E. Code (Par. P-268a or U-59a Revised) may be closed by the use of a patch or plate, at least 2 in. larger in diameter than the hole, placed on the inside of the drum or shell and sealed against leakage by fusion welding, preferably on both the inside and outside edges. Such patches shall not be set in the shell flush with the surrounding plate.

(*i*) Tubes of fire tube boilers may be re-ended or pieced by the fusion welding process provided such tubes are well distributed and their number does not exceed 50% of the total and further that there are no more than two circumferential welds in any one tube. Provided, however, that in fire tube boilers tubes that have been re-ended by the fusion welding process may be used in excess of 50% of the full number of tubes provided such re-ended tubes have been welded by operators who have demonstrated their ability to obtain sound and ductile welds. Satisfactory evidence of a welding operator's ability in this connection shall be obtained by having the welding operator make several sample welds between two pieces of boiler tubing, the welding to be done under the same conditions and by the same process as will be the case in the actual safe-ending of tubes. After such samples have been welded they shall be cut into longitudinal strips about 1 in. wide, the reinforcement of the weld on the outside, if any, ground off and the specimens then broken at the weld. This method of examination may be accomplished by gripping the specimen at the weld, in a vise, and the extended section driven backward with a hammer so that the weld will be opened at the root. To be satisfactory, welds broken in this manner shall be clean and properly fused through at least 90% of the thickness of the tube.

If more than 50% re-ended tubes are found in a boiler and it is impossible to have the welding operator who did the work make some sample welds for test, three tubes at various locations shall be removed from the boiler and the welds shall be subjected to the above test.

5. The repairing of tubes or headers in water tube boilers by fusion welding is not permitted.

6. Cracks in the shells or drums of power boilers, except as otherwise specified herein, shall not be welded.

7. The building up of grooved or corroded areas of unstayed internal surfaces, other than widely scattered pitholes, by means of deposited metal is not approved.

8. Leakage at riveted joints or connections must be carefully investigated to determine the cause of such leakage.

CURRENT WELDING LITERATURE

Aluminum Welding. Advances Made in Welding of Aluminum, G. O. Hoglund. Iron Age (Mar. 19, 1936), vol. 137, no. 12, pp. 46–47.

Aluminum, Welding of, G. O. Hoglund. Welding Engineer (Feb. 1936), vol. 21, no. 2, pp. 26–30.

Boiler Manufacture. Alternating-Current Arc Welding, O. A. Tilton and J. T. Phillips. Boiler Maker & Plate Fabricator (Mar. 1936), vol. 36, no. 3, pp. 54–58 and 60.

Bridges, Steel. Welded Bridges, G. Roberts. Elec. Welding (Feb. 1936), vol. 5, no. 27, pp. 90–94. Article discusses universal application of welding to bridges up to 300-ft. span, and gives brief summary of bridge welding so far completed, in various countries; notes on plate girder bridges, arch bridges, Vierendeel trusses, truss bridges, working stresses and butt-welds; shop and site welding.

Bronze Welding. Welding Bronze to Steel, C. H. Jennings. Mech. Eng. (Dec. 1935), vol. 57, no. 12, pp. 796–797.

Cars, Freight. Welded Underframes for Freight Cars, S. D. Baumer. Metal Progress (Mar. 1936), vol. 29, no. 3, pp. 41–43 and 88.

Construction Industry. Advances in Construction Practice. Civ. Eng. (N. Y.), vol. 6, no. 3 (Mar. 1936), pp. 139–157.

Conveyors, Screw. Screw Conveyors for Cement. Oxy-Acetylene Tips (Feb. 1936), vol. 15, no. 2, p. 33.

Copper Alloys. Developments in Welding of Copper Alloys, I. T. Hook. Iron Age (Feb. 20, 1936), vol. 137, no. 8, pp. 40–41.

Electric Welding, Arc. Effect of Welding Variables on Physical Properties of Electric Arc Weld Metals, R. R. Blackwood. Instn. Engrs. Australia—J. (Jan. 1936), vol. 8, no. 1, p. 14.

Electric Welding, Arc. Field of Arc Welding Expands, G. H. Hall. Elec. World (Feb. 1, 1936), vol. 106, no. 5, pp. 32–35.

Electric Welding, Arc. Some Thoughts on Development and Promotion of Arc Welding, LaM. Grover. Welding Engr. (Feb. 1936), vol. 21, no. 2, pp. 23–24.

Electric Welding, Resistance. Resistance Welding—II, L. H. Frost. Welding Engr. (Feb. 1936), vol. 21, no. 2, pp. 38–40.

Electric Welding, Resistance. Spot-Welding, E. J. L. Dussourd. Metallurgist (Supp. to Engineer) (Feb. 28, 1936), pp. 98–99.

Electric Welding Machines. Arc Welding Apparatus. Development in Arc Welding, E. Steinert and W. W. Reddie. Iron & Steel Engr. (Jan. 1936), vol. 13, no. 1, pp. 9–12.

Electroplating Shops. Fabricating Large Plating Tank, V. D. Green. Boiler Maker & Plate Fabricator (Mar. 1936), vol. 36, no. 3, pp. 59–60.

Forge Shop Practice. Forge Welding with Water Gas, J. B. Nealey. Heat Treating & Forging (Feb. 1936), vol. 22, no. 2, pp. 89–91.

Forgeability of Welded Joints, H. Becker. Mech. Eng. (Feb. 1936), vol. 58, no. 2, p. 126.

Iron and Steel. Bonding Ferrous Metals by Heat and Pressure, L. C. Grimshaw. Steel (Feb. 24, 1936), vol. 98, no. 8, pp. 49 and 51–54.

Iron and Steel. Electrolytic Iron Provides Bond in Cladding with Special Alloys, R. R. Rogers. Steel (Feb. 10, 1936), vol. 98, no. 6, pp. 34–35.

Metallurgical Trends of Chemical Engineering Interest, C. E. Williams. Chem. & Met. Eng. (Jan. 1936), vol. 43, no. 1, pp. 17–19.

Oil Well Drilling. Welding Hard-Facings on Drilling Tools, J. Cuthill. Instn. Petroleum Technologists—Advance Paper mtg. Feb. 11, 1936, pp. 1–6, 4 supp. plates.

WELDING SOCIETY ACTIVITIES AND RELATED EVENTS

Annual Meeting Combined with Fall Meeting

As indicated elsewhere in this issue, the membership of the Society has ratified a change in the By-laws, which does away with the Annual Meeting and combines the business sessions with the Fall Meeting.

This year the Combined Fall and Annual Meeting will be held in Cleveland during the week of October 19th in connection with the Metal Congress Exposition.

The Tentative Program, already taking shape, assures one of the most interesting sessions ever held by the Society. One of the days will be arranged for a joint symposium with the American Society of Mechanical Engineers.

The opening session on Monday, October 19th, will be the usual business session which formerly took place in April. At this time the President's report of the year's activities will be read and the election of officers announced. The technical sessions will start Monday afternoon, Oct. 19th, and will continue on through Thursday, Oct. 22nd. The Board of Directors' dinner will be held Monday evening and the Fundamental Research Conference will be held Tuesday evening. It is planned to hold the annual banquet of the Society on Thursday, Oct. 22nd.

Proposed Federal Specification

The Federal Specifications Division has issued suggested specifications for Steel, Structural (Including Steel for Cold Flanging), and Steel, Rivet; (For) Ships other than Naval Vessels; Metals, General Specification for Inspection of. All comments or criticisms must be received by the Federal Specifications Division, Room 751, Federal Warehouse, 9th and D Sts., S. W., Washington, D. C., not later than April 14, 1936.

Another Use of Arc Welding Apparatus

During the recent cold weather a large number of cars failed to start because of run down batteries. If a D.C. welding set terminals are applied to the battery, positive to positive, negative to negative, and the voltage brought up slowly after a good connection has been made, there is more power to start an automobile engine than could ever be available from any battery. Once the engine starts, the battery will pick up.—*C. J. Holslag, Electric Arc Cutting & Welding Co.*

M. Bayard Butler, Jr.

It is with great regret that we must report the death of one of the leading members of the AMERICAN WELDING SOCIETY, M. Bayard Butler, Jr., on Sunday morning, March 8th. Mr. Butler was burnt to death in a fire that swept the dormitory rooms on the fifth floor of the Camac Baths, Philadelphia. Although over a hundred people escaped, Mr. Butler's escape was prevented by a chronic throat condition which was an outgrowth of a gasing suffered in a U. S. Submarine during the War. Mr. Butler was in the employ of the Edward G. Budd Manufacturing Company, High Tensile

Division, where he was an important factor in the development of the application of shot-welding stainless steel to light-weight construction, to railroads, shipyards, aircraft and truck bodies. Mr. Butler was known in the industry as an expert in the resistance welding field.

He was born on October 7, 1891, in Bridgeport, Conn. He was graduated from the Carnegie Institute of Technology in 1913 with the degree of B.S. in E.E. From 1913–1917 he was connected with the Duquesne Steel Works of the Carnegie Steel Company in various engineering capacities. In 1917 he joined the U. S. Navy and served as Chief Electrician, Ensign and Lieutenant. He was active in engineering work in the Navy and particularly in submarines. He also served as an instructor in the Navy. It was in connection with submarine duty that he suffered from a gasing which was later to be instrumental in his death by preventing escape during the fire. From 1919 to 1925 he served several companies as engineer and consultant. From 1925 to 1929 he was connected with the American Chain Company, in charge of all electrical work in nine of their plants. The work included the development of automatic electric welders for making chains. From 1929 to 1931 he served as mechanical engineer on the design and installation of high-pressure equipment for the DuPont Ammonia Corporation.

For a short duration he worked for the Engineering Division of the National Research Council as a special research investigator and at that time was also active in assisting with the work of the AMERICAN WELDING SOCIETY.

One of the important factors contributing to Mr. Butler's success was his remarkable personality. He was well liked by all the members, a good mixer and at all times ready to participate and do his share either in work or play.

Mr. Butler is survived by his mother, father, wife, a son and sister.

EMPLOYMENT SERVICE BULLETIN

POSITION VACANT

V-67. WELDING SERVICE MAN wanted for traveling out of New York headquarters. Some correspondence to handle. Applicants should be high school graduates. Personality, ability to discuss welding and demonstrate to welders and shop superintendents. Intimate familiarity and ability to weld the strong, corrosion-resistant alloys, and a knowledge of fabrication of chemical plant and other heavy equipment is desired. Applications should include details of experience, salary desired and references.

V-68. Company desires an intelligent, skilled Arc Welder for laboratory work in connection with development of coatings for electrodes. Location Niagara Falls. Give full details.

SECTION ACTIVITIES

BOSTON

On Friday, April 17th, the members of the Boston Section have the opportunity of visiting the Bethlehem Shipbuilding Corporation's Fore River Plant in Quincy. Starting at 2:30 P.M. from the main office, the group will be conducted through the various shops and yards, and at 6 P.M., dinner will be served at the Plant. The charge for the dinner will be 75¢ a person. The evening program will consist of talks by several representatives of the Fore River Plant.

CHICAGO

The Midwest Power Engineering Conference will be held in Chicago, April 20th–23rd. One of the papers on Wednesday, April 22nd, in the morning will be "Welding of Alloy Steels and Pipe," by J. R. Dawson, Union Carbide Research, Inc., Niagara Falls, N. Y.

The March meeting of the Chicago Section was held on the 27th in Armour Institute of Technology. A lecture course on "Metallurgy as Applied to Welding," was presented by Mr. Jules Muller of the Chicago Steel and Wire Company. Sound motion picture on the manufacture, fabrication and application of "Enduro" Stainless Steels, was shown, with a talk by Mr. V. W. Whitmer, Metallurgist, Republic Steel Corporation. The film showed the mining of nickel and chromium, the manufacture of stainless steel sheets, and fabrication by welding, soldering, spinning, drawing, stamping and forming.

"Welding of Nickel, Nickel-Clad Steel, Inconel and Monel Metal," was presented by Mr. F. G. Flocke of the Development and Research Dept., The International Nickel Co. Inc.

CLEVELAND

The Fifth regular monthly meeting of the Cleveland Section was held at the Cleveland Engineering Society on March 18th. Mr. J. C. Holmberg, Metallurgist, Struthers-Wells-Titusville Corp., presented an outstanding and most interesting paper on the subject "Welding Developments."

DETROIT

Monthly meeting of the Detroit Section was held on March 27th at the Taylor-Winfield Corp. Plant, Highland Park. Mr. M. S. Clark, General Manager of the Taylor-Winfield Corp., spoke on the topic "March of Welding," a discussion of recent developments in resistance welding, including welding of aluminum and various alloys, percussion welding and multi-spot welding, which was accompanied by a complete demonstration set-up on all types of machines.

LOS ANGELES

The regular monthly meeting was held on February 20th at the Los Angeles Chamber of Commerce Building. Fifty-five members and guests attended. Dinner was served at 6:30 P.M., after which the meeting was called to order. The first speaker of the evening was Mr. F. C. Fantz, Vice-President, Midwest Piping and Supply Co. Mr. Fantz gave an extremely interesting talk on the practical aspects of "Welding as Applied to Pipe Fabrication." He stressed the point that a weld is no better than the organization that produces it.

The second speaker was Mr. Fred Huston, Development Engineer, International Nickel Co. His talk on "Fabrication of Clad Steel Plate" discussed the development of manufacturing methods and procedure for fabrication of clad plate. It was illustrated by slides.

Each of these talks was followed by an interesting and enlightening discussion.

The March 19th meeting was held at the Los Angeles Chamber of Commerce Building. After dinner the meeting was called to order by Chairman Blake. The first speaker was Mr. L. Lowell Johnson, Credit Union Section, Farm Credit Administration, Washington, D. C. Mr. Johnson spoke on non-metallic welding, welding the bonds of financial security through cooperative effort of fellow workers. This talk presented the history and organization of credit unions in a vivid manner which occasioned extensive discussion. The second speaker was Mr. Wilson P. Hunt Vice-President, Moline Tool Company. His talk on "The Effect of Welding Practice on Machine Tool Structures" presented a concise picture of composite machine design.

MILWAUKEE

The guest speaker at the last meeting of the Milwaukee Section of the Society of Automotive Engineers on March 2nd was Mr. K. L. Hansen, consulting engineer for the Harnischfeger Corporation and nationally known authority on welding. Mr. Hansen's interesting talk, illustrated with slides, was devoted to new trends in the application of welding in the heavy machinery and automobile industries.

NEW YORK

"Welding Practice in the Bureau of Navigation and Steamboat Inspection" will be the subject of the April 14th meeting of the New York Section which will be held in the Engineering Societies Building. Mr. James W. Wilson, Traveling Inspector, will address the meeting.

The next meeting of the Section will be a joint meeting with the American Society for Metals at the Hotel Pennsylvania on April 20th. Subject: "The Thermal Treatment of Welds," by J. C. Hodge.

PHILADELPHIA

Dr. J. C. Hodge of the Babcock & Wilcox Company, addressed the March 16th meeting of the Philadelphia Section, on the subject "Fundamentals of Good Welding," which was both interesting and instructive.

PITTSBURGH

The March 18th meeting of the Pittsburgh Section, at which Mr. H. M. Priest, Engineer of the United States Steel Corporation was scheduled to speak, was canceled due to flood waters. A new date for this meeting will be announced later.

SAN FRANCISCO

The regular meeting of the San Francisco Section was held at the Athens Club in Oakland, on February 28th. Report of the Nominating Committee was read and the results of the election will be announced at the April meeting. Mr. Edgar Booker, Metallurgist for the Standard Oil Company, spoke on the subject of "Underwater Welding." Mr. Booker's presentation though brief was very well received and an interesting discussion followed.

The March meeting was held at the Humboldt Evening High School, on the 20th. The meeting was opened at 7:30 P.M. with a Sound Picture of the construction of the Oakland–San Francisco Bay Bridge. The picture was furnished through the courtesy of the Columbia Steel Corporation. This was followed by a technical paper on the subject "Hydrocarbon Fuel Gases for Cutting," by Dr. G. V. Slottman, Applied Engineer, Air Reduction Sales Co. The paper was illustrated with slides.

By-Law Amendments Effective April 10, 1936

Article IV

Officers, Nominations and Elections

Sec. 6.—Nominations and elections of the Officers shall proceed as follows:

(*a*) The Secretary shall mail on or before the first Tuesday in June of each year to each member entitled to vote a notice that nominations for Officers must reach the Secretary not later than the first day of July. This notice shall outline the vacancies of elective offices that shall be filled at the next regular election and request nominations for such offices. This notice shall contain a copy of this Section and the list of nominees recommended by the Nominating Committee and information that no name shall appear on the final voting ballot unless proposed by at least 25 qualified members. The notice shall also contain the names of the members of the Nominating Committee.

(*b*) The nomination blank must be placed in a plain envelope and sealed; then inserted in a second envelope and sealed. The voter will then write his name thereon in ink and mail it to the Secretary. The Secretary will certify to the competence and signature of all voters returning endorsed nomination ballots and will then deliver them to the Nominating Committee.

A Nomination ballot without autographic endorsement of the voter written on the outside envelope is defective and shall not be canvassed by the Nominating Committee. The Nominating Committee shall first open and destroy the outer envelopes of all properly endorsed ballots and shall then open the inner envelopes, canvass the ballots and certify the results to the Secretary. If no nominations, other than proposed by the Committee, are made by 25 qualified members, then the Secretary shall treat the nomination ballots as Election Ballots and certify the results to the Presiding Officer at the first session of the Annual Meeting.

(*c*) If a member, not proposed by the Nominating Committee, is duly nominated as provided for in paragraph (*a*) of this Section then the Secretary shall mail on or before the first Tuesday in July of each year to each member entitled to vote a ballot stating the names of the candidates for the several offices falling vacant and the time of the closure of the voting. The voter shall prepare the ballot by indicating by means of a cross opposite the name of each candidate he wishes to vote for. The voter shall enclose said ballot in an envelope and seal same. He shall then enclose the sealed envelope in a second envelope marked "Ballot for Officers,"

seal same and write his name thereon in ink, for identification. The ballot thus prepared and enclosed shall be mailed or delivered unopened to the Tellers of Election.

The Secretary shall certify to the competence and signatures of all voters. A ballot without the autographic endorsement of the voter written on the outside envelope is defective and shall be rejected by the Tellers of Election. A ballot which has choice indicated for more names than there are offices to be filled is defective and shall be rejected by the Tellers.

Sec. 7.—The voting for the election of officers shall close at 1 o'clock in the afternoon on the first Thursday in August of each year. The Tellers shall not receive any ballot after the stated time for the closure of voting. The Tellers of Election shall first open and destroy the outer envelopes and shall then open the inner ones, canvass the ballots and certify the results to the Presiding Officer at the first session of the current meeting of the Society. The Presiding officer shall then announce the candidates having the greatest number of votes for their respective offices and declare them elected for the ensuing year.

Sec. 11.—Tellers of Election. The President shall, on or before the first Thursday in August of each year, appoint three Tellers of Election of Officers, whose duty shall be to canvass the votes cast, and certify the same to the President, or Presiding officer, at the first session of the Annual Meeting. Their term of office shall expire when their report of the canvass has been presented and accepted.

Article V

Duties of Officers

Sec. 2.—The President shall preside at all meetings of the Society and of the Board of Directors; he shall have general active management and supervision of the affairs of the Society; shall see that all orders and resolutions of the Board are carried into effect; shall attend generally to its executive business and the supervision and direction of all the other Officers in the proper performance of their respective duties; shall submit a report of the operations of the Society for the fiscal year to the Directors at their last regular meeting preceding the Annual Meeting, and to the members at the Annual Meeting and from time to time shall report to the Board all matters within his knowledge which the interests of the Society may require to be brought to their notice; shall be, ex-officio, a member of all standing committees; and shall have the general powers and management usually vested in the office of the President of the Society.

Article VII

Committees

Sec. 1 (e).—A Nominating Committee of seven members. Announcement of the appointment shall be made by the President through publication in the JOURNAL on or before March 1st. The Committee shall consist of a chairman who shall be a Past-President of the Society and six members (not members of the Board of Directors), one of whom shall be a Past-President of the Society. The Committee shall deliver to the Secretary in writing on or before the last Tuesday in May, the names of its nominees for the various elective offices next falling vacant together with the written acceptance of each nominee.

Article VIII

Meetings and Notices

Sec. 1.—There shall be an Annual Meeting of the Society each year for the election of Officers and other business, held sometime in the Fall of the year at such time and place as may be decided by the Board of Directors. Other meetings may be called at the discretion of the Directors.

Summary* of Replies Received to Questionnaire of Meetings and Papers Committee up to April 1st

Fields of Interest

Maintenance and Repair	234
Construction	325
Production	298
Research	331

Type of Papers

Apparatus	169
Design Methods and Data	354
Techniques, Procedures	326
Economics	167
Test Results	241
Metallurgy	289
Filler Metal	180
Theory	198
Specification and Codes	247
Inspection, Training	256
Acceptance Requirements	139
Safety	149
News and Pictorial Reviews	144

Metals

Low Carbon Steel	386
Alloy Steel	386
High Carbon Steel	222
Cast Iron	167
Cast Steel	195
Non-ferrous Metals	250

Welding Processes

Arc	515
Gas	253
Resistance	191
Thermit	78
Cutting	233

Applications

Aircraft and Automotive	128
Shipbuilding and Repair	181
Railroad and Railway	180
Pipe Lines and Piping	254
Pressure Vessels	301
Welding Shop & Maintenance Problems	242
Tanks	252
Structural Steel & Bridges	277
Light Gage Production Work	173
Machinery	194
Hard Facing and Surfacing	191
Steel Mills	113
Metal Spraying	142
Low Temperature Brazing	113
Bronze Welding	149

* Major interest counted as two votes, minor interest one vote.

Translations

"Results of Fatigue Strength Tests on Welded Connections," by Dr. Ing. Kommerell, has been made possible through the courtesy of the American Institute of Steel Construction. Members desiring to secure copy may do so by applying at the office of the AMERICAN WELDING SOCIETY. There will be no charge for this important paper as long as copies last.

The Society possesses two copies of a translation of a paper "On Stresses in Welds" by Dipl. Ing. A. Sonderegger, Zurich, translated from "Zeitschrift fur Schweisstechnik" 1933, No. 3 and No. 4. These copies will be loaned upon request.

XIIth International Congress

The XIIth International Congress of Acetylene, Oxyacetylene Welding and Allied Industries, will be held in London, June 8–13, 1936. Members of the Society desiring to attend the Congress should get in touch with the Secretary of this Society or the General Secretariat, 639, Grand Buildings, Trafalgar Square, London, W. C. 2.

Fusion Welding of Highway and Railway Bridges

A Specification for the Design, Construction, Alteration and Repair of Highway and Railway Bridges by Fusion Welding, has been prepared by a committee of the AMERICAN WELDING SOCIETY. It occupies 66 pages with a number of sketches. Unit design stresses are included. Price $1.00 per copy (25% discount to members).

The Bridge Specification prescribes unit stresses varying with the range of stresses in a manner similar to those adopted in one or two European countries but expressed much more simply and in a manner that will lend itself readily to amendment when American fatigue testing produces more dependable data. Special credit is due to the Chairman of the Committee, individual members and chairmen of subcommittees.

The rapid development in welding during the past four years makes it imperative to exercise sound engineering judgment and clear thinking when evaluating the information available. The fundamental principles of welding are such that there are no precedents that can be adopted from other forms of construction, and it therefore follows that creative originality and inventive genius are necessary in the engineer engaged in the design and construction of welded bridges.

"MY PROBLEM IS DIFFERENT! I USE LIGHT GAUGE METALS"

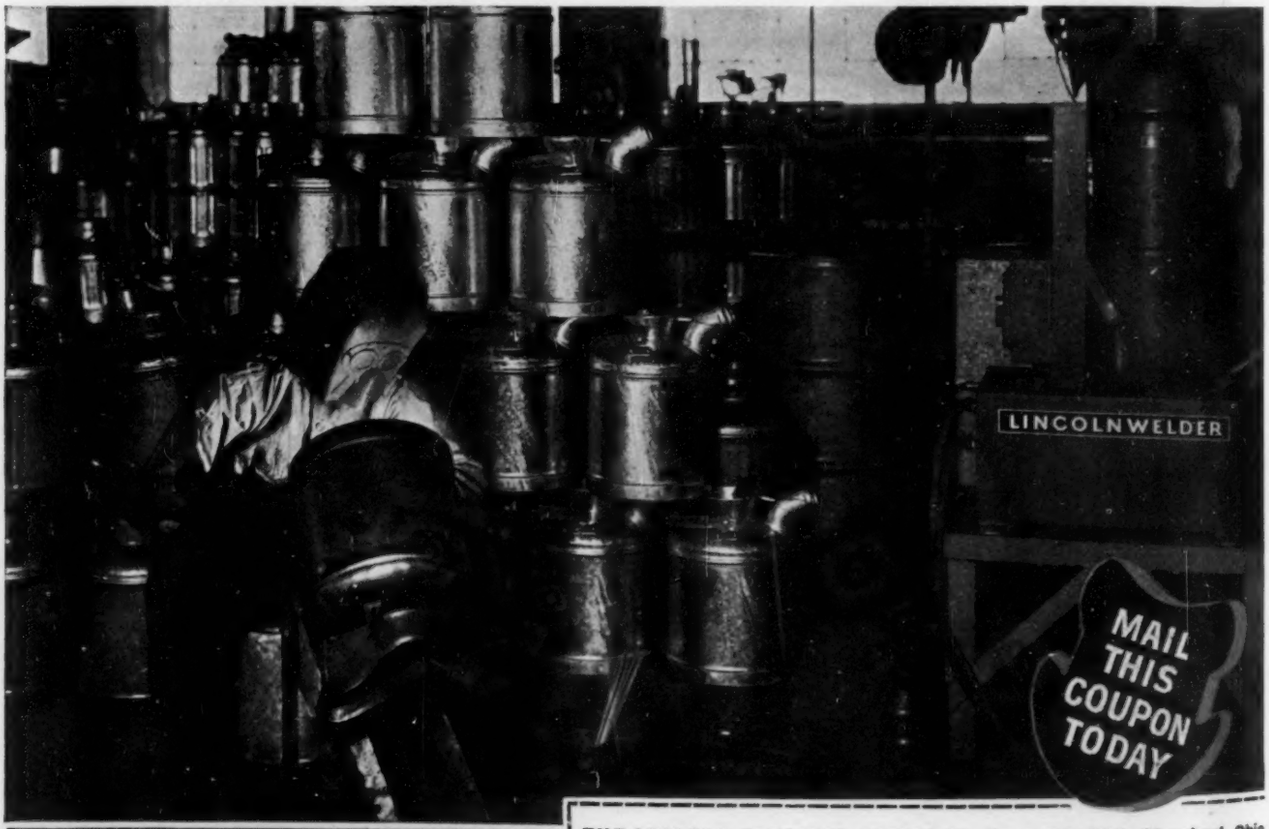
"YOUR PROBLEM IS SIMPLE! NOW *LIGHT GAUGE METAL* WELDING IS DIFFERENT!"

Sheet metal welding was never so practical as it is now with the new Lincoln 75 ampere and 100 ampere outfits. Nor has it ever been so economical. (Users report power costs as low as 5c an hour.)

A highly concentrated arc heat, fully controlled, permits speedy welding of steel or alloy sheets as light as 24 gauge. Buckling and warping...and burn-throughs...now can be avoided readily. A wide range of current values makes these machines adaptable to heavier materials as well... such as cast iron, aluminum and non-ferrous alloys.

The price? As low as $200. Convenient deferred payments can be arranged. Get the production advantages and savings which this value makes possible! The coupon will bring you details. THE LINCOLN ELECTRIC COMPANY, Dept. DD-220, Cleveland, Ohio. Largest Manufacturers of Arc Welding Equipment in the World.

Welding bottoms in gasoline cans of 18 and 20-gauge steel with the Lincoln 100-amp. welder. Photo courtesy of Columbian Steel Tank Co., Kansas City, Mo.



Largest Manufacturers of Arc Welding Equipment in the World

LINCOLN

THE LINCOLN ELECTRIC COMPANY, Dept. DD-220, Cleveland, Ohio

I am interested in the new Lincoln Sheet Metal Welder.
Please send me complete description and payment details.

Firm .....

Name ..... Position .....

Address .....

City ..... State .....

Our Advertisers Are Supporting the Society